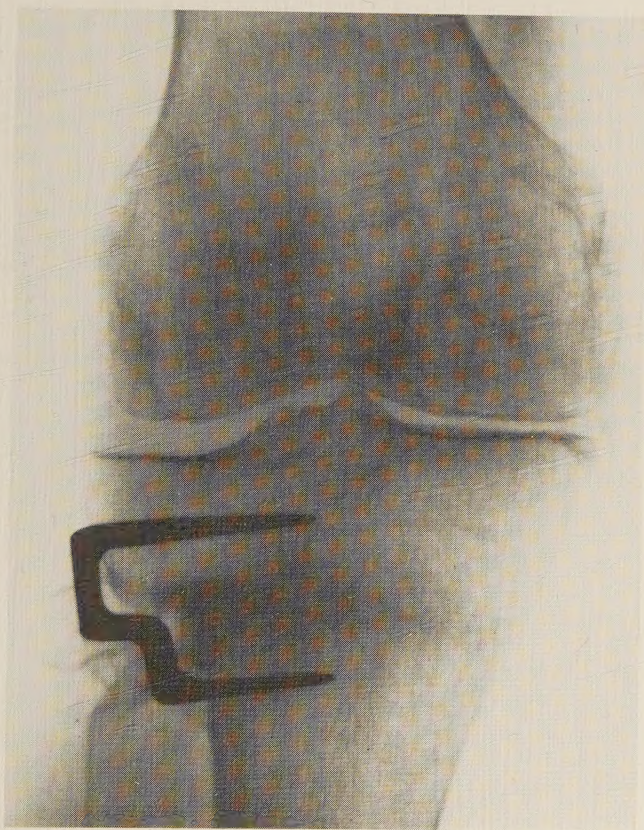


TIBIAL OSTEOTOMY for MEDIAL GONARTHROSIS



Björn Tjörnstrand

Lund 1981



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TIBIAL OSTEOTOMY for MEDIAL GONARTHROSIS

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INTRODUCTION

The treatment of gonarthrosis has become increasingly vigorous during the past 30 years. Prior to the introduction in the late 1950s of osteotomy for the correction of varus or valgus deformity, none of the methods could claim any lasting effect on pain and knee function. Jackson (1958) and Bouillet and van Gaver (1961) demonstrated the effects of osteotomy, and the operation became widely accepted in the 1960s when the reasons for its effects became understood. Maquet et al. (1966) demonstrated the effects of high asymmetric loads on the femoro-tibial articulation caused by angular deformity. Ahlbäck's (1968) radiographic examination of gonarthrosis in weight-bearing positions demonstrated the focal nature of arthrosis as distinct from rheumatoid arthritis, and the sequence of events in the development of gonarthrosis. The increased understanding of the biomechanics of gonarthrosis (Bauer et al. 1969) explained the flaws of previous methods of treatment, none of which corrected the mechanical axis of the knee. Patellectomy and the "house-cleaning" operation (Magnusson 1946) were done for removal of osteophytes which Ahlbäck (1968) showed were at best of tertiary importance in the development of the disease. Radiotherapy and corticosteroid injections were shown to be harmful rather than beneficial (Goldie et al. 1970, Salter et al. 1967, Moskowitz et al. 1970).

In the 1970's, prosthetic arthroplasty rapidly developed into a strong competitor with osteotomy for the treatment of gonarthrosis. Arthroplasty became the preferred treatment for the most advanced stages of medial gonarthrosis (Hagstedt 1974, Coventry 1979, Jónsson 1981) and for even moderate stages of lateral arthrosis (Shoji and Insall 1973, Hagstedt 1974). However, Hernborg and Nilsson (1977) demonstrated the relentless progression of gonarthrosis so that, once established, even mild cases eventually have a poor prognosis. The preventive potential of the tibial osteotomy became apparent, but the operation could be advocated in early cases only if correction could be achieved with high precision; under-correction was a common result of the operation (Hagstedt 1974).

Purpose of this investigation

The investigation summarized here is a direct extension of Hagstedt's (1974) review of a consecutive series of 166 tibial osteotomies performed in Lund and followed-up for 1-2 years. Hagstedt in turn based his work on Bauer et al. (1969), who at the Hospital for Special Surgery in New York had demonstrated that the effect of the tibial osteotomy is directly related to correction of angular deformity. The purpose of this investigation was:

- to evaluate the long-term effects of high tibial osteotomy on pain, function and the articular cartilage;
- to increase the accuracy of correction of the mechanical axis by improved preoperative radiography and surgical precision;
- to evaluate the treatment of pseudarthrosis after tibial osteotomy.

To this end:

- Hagstedt's (1974) patients have been followed-up for another five years;
- improved radiographic and surgical techniques have been applied to two series of knees with arthrosis restricted to the medial compartment;
- the accuracy of the radiographic and surgical procedures was assessed by roentgen stereophotogrammetry.

In order to define the place of osteotomy in the treatment of gonarthrosis the observations in this investigation were discussed with reference to a parallel investigation of unicompartment arthroplasty in gonarthrosis (Jónsson 1981) and with previously published data on arthroplasty of the knee.

Detailed results of this investigation are published in papers I - V.

- I Tjörnstrand, B., Egund, N., Hagstedt, B.: High tibial osteotomy. A seven year clinical and radiographic follow-up. Accepted for publication in *Clinical Orthopaedics*.
- II Hagstedt, B., Norman, O., Olsson, T.H., Tjörnstrand, B.: Technical accuracy in high tibial osteotomy for gonarthrosis. *Acta Orthop. Scand.* 51:963-970, 1980.
- III Tjörnstrand, B., Egund, N., Hagstedt, B., Lindstrand, A.: Tibial osteotomy in medial gonarthrosis. The importance of over-correction of varus deformity. Submitted for publication.
- IV Tjörnstrand, B., Selvik, G., Egund, N., Lindstrand, A.: Roentgen stereophotogrammetry in high tibial osteotomy for gonarthrosis. Submitted for publication.
- V Tjörnstrand, B., Hagstedt, B., Persson, B.: Results of surgical treatment for non-union after high tibial osteotomy in osteoarthritis of the knee. *J. Bone Joint Surg.* 60-A:973-977, 1978.

DEFINITIONS USED IN THIS WORK

Planes

The frontal plane is vertical and goes through or parallel to the tangent of the dorsal aspects of the two femoral condyles (II).

The sagittal plane is vertical and perpendicular to the frontal plane.

The transverse plane forms a right angle with both the frontal and the sagittal planes.

Axes

The femoral or tibial anatomical axis is the longitudinal axis of the diaphysis in the frontal plane.

The femoral mechanical axis lies in the frontal plane and connects the centers of the femoral head and the femoral intercondylar groove.

The tibial mechanical axis lies in the frontal plane and connects the centers of the tibial eminence and the ankle joint.

The mechanical axis of the lower limb lies in the frontal plane and connects the centers of the femoral head and the ankle joint; normally this axis transects the center of the tibial eminence (Maquet et al. 1967).

Angles

The FT-angle is the lateral angle between the anatomical axes of the femur and the tibia.

The TT-angle is the lateral angle between the tibial anatomical axis and the tangent of the tibial articular surfaces in the frontal plane.

The TTS-angle is the posterior angle between the tibial anatomical axis and the tangent of the tibial articular surfaces in the sagittal plane.

The angular deviation of the mechanical axis is the angle between the femoral and tibial mechanical axes in varus or valgus when the mechanical axis of the lower limb falls medial or lateral to the center of the tibial eminence.

Rigid body displacements

Translation of a point is a change in its position. A pure translation of a body causes parallel translation of all its points.

Rotation does not cause translation of points on a line (the rotation axis); points outside this line translate in proportion to their distance from the line.

Table 1. Series of patients studied.

Series	Period	Number of knees	Sex		Type of arthrosis		Mean age at operation
			Men	Women	Medial	Lateral	
I	1969-72	107	29	78	89	18	65
II *	1975-76	66	31	35	66	-	56
III *	1976-78	52	30	22	52	-	56
IV	1980	3	2	1	3	-	55
V	1969-74	12	2	10	11	1	69
Total *		229	86	143	210	19	60

* The last 11 knees in series II were included in series III.

MATERIAL

At the Lund University Hospital, Department of Orthopaedics in Lund 419 tibial osteotomies were performed for gonarthrosis during 1969-80 (Fig. 1). All knees from 1969-72 and all knees with medial arthrosis from 1975-78 were subjected to prospective analysis. In addition, the Department of Orthopaedics, Eksjö General Hospital, contributed 17 cases of tibial osteotomy for medial gonarthrosis operated between 1976 and 1978 (Table 1).

721 OPERATIONS FOR GONARTHROSIS

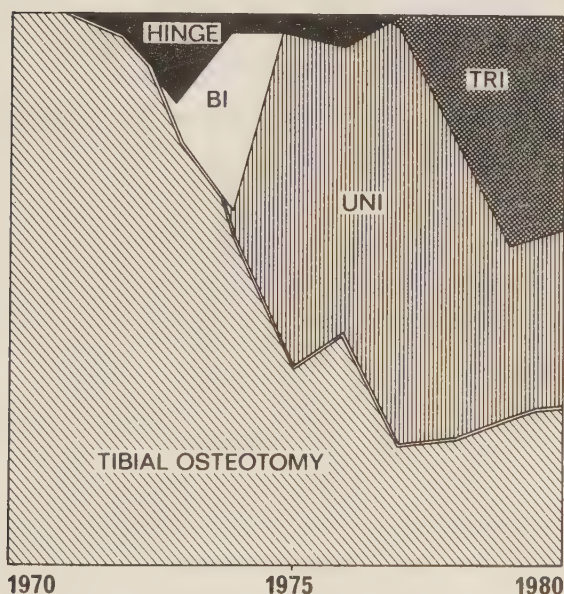


Fig. 1. Breakdown of operations for gonarthrosis during the period 1970-1980. Osteotomy decreased when the knee prostheses were introduced; since 1977 the osteotomy fraction has constantly been one quarter of the operations. Uni-, bi-, and tri- stand for unicompartmental etc endoprotheses. Hinge means hinge endoprotheses.

First, long term prospective series (I) of the earliest cases comprised 107 knees in 99 patients, first reported by Hagstedt (1974) 1-2 years after the

operation. 89 knees had medial arthrosis, 13 of these also had patellar arthrosis, and 18 knees had lateral arthrosis. The mean age at the time of operation was 65 years and the material was reviewed on average 7 years after the initial operation.

Second prospective series (II) comprised 66 knees operated on in 1975-76 for medial type gonarthrosis up to Stage III (Ahlbäck 1968) in patients under the age of 65 years.

Third, over-correction prospective series (III) consisted of a consecutive series of 52 knees operated on in 1976-78; the first 11 knees also belonged to the first prospective series. The selection of cases was the same as in this earlier series but the operation now aimed at over-correction in valgus.

Roentgen stereophotogrammetry (IV) was performed in three knees with medial arthrosis.

The pseudarthrosis series (V) contained 10 knees osteotomized in Lund 1969-74 and two knees referred from other hospitals; since 1975 we have had no pseudarthroses following tibial osteotomies in Lund.

METHODS

Since high tibial osteotomy for gonarthrosis was introduced in Lund in 1969 all patients have been analysed in uniform fashion before and after operation by clinical and radiographic methods. Certain parameters have been added to the original protocol, notably radiographic measurements of the mechanical axes and stereophotogrammetry.

Clinical examination and evaluation

Mobility. The range of motion was recorded with the aid of a goniometer. A knee with at least 90° of flexion and up to 5° loss of extension was defined as mobile.

Stability. A knee without medial or lateral thrust on walking (Hagstedt 1974) was defined as stable.

Laxity was tested by passive movement in the frontal plane with the knee extended.

Pain was recorded at rest and on walking. Pain at rest was subdivided into no pain, pain after exercise, and continuous pain. Pain on walking was divided into seven stages with the worst being pain arising with the first step. Pain relief was recorded for those knees which had improved their pain-free walking distance to more than 100 m.

Pain-free was recorded for those knees which permitted a pain-free walking distance of more than 500 m; this category was used also when there was no pain in the knee on walking but limitations were imposed for other reasons.

Good function. Those knees which were mobile, stable and had pain relief were defined as having good knee function (I).

Satisfactory function. Those knees which were mobile, stable and pain-free were defined as having satisfactory knee function (II).

Radiographic examination and evaluation

Type and stage of arthrosis. On radiographs of knees stressed in varus and valgus (Norman 1974) each compartment was evaluated to distinguish between medial and lateral femoro-tibial arthrosis (Ahlbäck 1968). In each type the stage of arthrosis was recorded as follows:

Stage I. Narrowing of the joint space;

Stage II. Obliteration of the joint space;

Stage III. Minor bone attrition of less than 0.5 cm;

Stage IV. Moderate bone attrition of less than 1 cm;

Stage V. Major bone attrition of more than 1 cm.

Subluxation of the femur in the frontal plane was a common feature in Stage V because of the bone loss but could appear in earlier stages, probably also because of ligamentous laxity.

Patellar arthrosis. The patello-femoral articulation was examined with the knee in flexion and the central beam parallel to the longitudinal axis of the patella.

A whole limb radiograph was taken in a defined frontal plane (II). The film focus distance was 2 m and the beam was centered on the middle of the knee. The correct frontal plane was identified from a lateral projection by an ordinary radiograph or by fluoroscopy.

Measurements of the correction. The size of the wedge to be removed was decided from the preoperative whole limb radiograph and the deviation angle of the mechanical axis. In the second prospective series the angle of the wedge was equated with the deviation angle, and in the third prospective series 4° was added. The wedge was drawn on the radiograph. The distance on the lateral cortex was then measured and used at the operation.

For the earliest series (I) the calculation of the wedge was made on short radiographs of the distal femur and proximal tibia obtained in standing position. The FT-angle was measured and the deviation from the normal value of 174° was used as the angle of the wedge. The vertical height of the wedge was calculated as 1° equal to 1 mm (Boulliet and van Gaver 1961).

At follow-up the change of the deviation angle of the mechanical axis represented the correction obtained, thus including both osseous correction and ligamentous laxity. The initial correction was measured on tibial radiographs taken through the plaster. The change of the TT-angle reflected the osseous correction, equivalent to the wedge of bone removed.

Roentgen stereophotogrammetry permits highly accurate measurements provided distinct reference points are available (Selvik 1974). Such points were provided by tantalum balls, 0.8 mm in diameter, implanted in the tibia before the operation, above and below the osteotomy site. The knees were examined loaded and unloaded pre- and postoperatively. The tantalum balls were identified on the films and their three-dimensional co-ordinates were determined. The method was used here to follow the displacements at the operation and during the healing process. This gave information of the accuracy of the surgical procedure and the conventional radiographic measurements.

The operation

In all cases a high tibial closing wedge osteotomy was performed under a tourniquet. In some cases reoperations for loss of correction were made below the tibial tubercle (V). Before 1975 a transverse incision was used, and all of the proximal tibia was exposed before making the osteotomy. The fibula was then handled in different ways, divided at different levels but mostly the fibular head was partly resected (Coventry 1965), allowing the osteotomy to close.

Since 1975 (II, III, IV) the skin incision was made between the tibial tubercle and the fibular head. The fascial and periosteal structures on the medial side were kept intact, serving as a hinge when closing the osteotomy, which was made from the lateral side with an oscillating power saw. Fluoroscopy controlled the position of the wedge; the proximal cut was parallel to the joint line and it met the distal cut just inside the medial cortex that was broken when the osteotomy was closed (Gariépy 1964, Coventry 1965). After 1975 a Coventry staple was used laterally in all cases; prior to 1975 half of the cases were operated without a staple.

Postoperative course. A plaster was applied from the groin to the ankle. The ankle joint was free and the patient was encouraged to bear weight from the first day. Radiographic controls were made the day after the operation, after 1 week when the plaster usually was changed to obtain a better fit, when the plaster was removed at 6-8 weeks, and then at intervals until the osteotomy had healed radiographically.

RESULTS

The lateral type of gonarthrosis was excluded from these results except in the section on the type of arthrosis in the seven-year series.

First, long term prospective series (I)

Type of arthrosis. Medial cases did better than lateral. Out of 89 medial cases 45 were good and 44 were not good; eight of the not good had had a further operation for prosthetic replacement. Out of 18 lateral cases only six were good and 12 were not good; six of the not good had had a further operation with prosthetic replacement in four cases and arthrodesis in two cases.

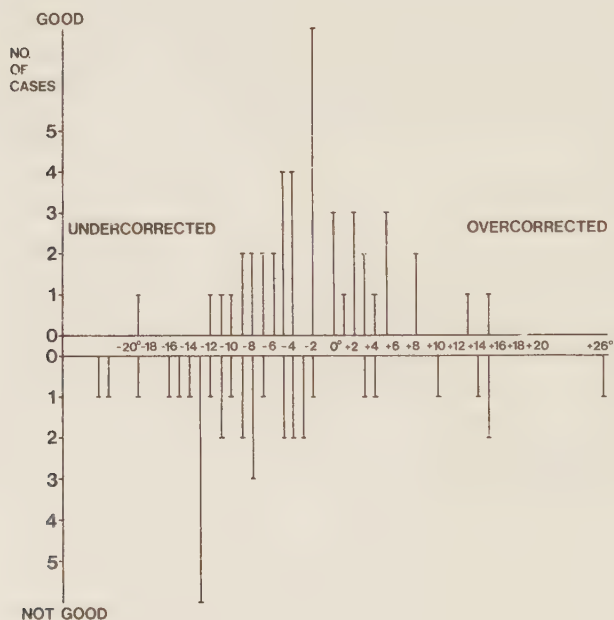


Fig. 2. Deviation angle of the mechanical axis of the knee seven years or more after high tibial osteotomy for correction of medial gonarthrosis in 81 cases. A deviation angle of 0° is present when the axis transects the tibial eminence.

Clinical outcome and correction of the mechanical axis (Fig. 2). At the seven year follow-up of the medial cases the mechanical axis lay in varus in 57 knees, in 0-9° valgus in 17 knees and in more than 10° of valgus in seven knees. In the 26 knees which were fully corrected or had less than 2° of under-correction all but three were good. In the 45 knees which were under-corrected by 3° or more or were over-corrected by more than 10°, the majority were not good. The mechanical axis had not been corrected in any of the eight reoperated knees.

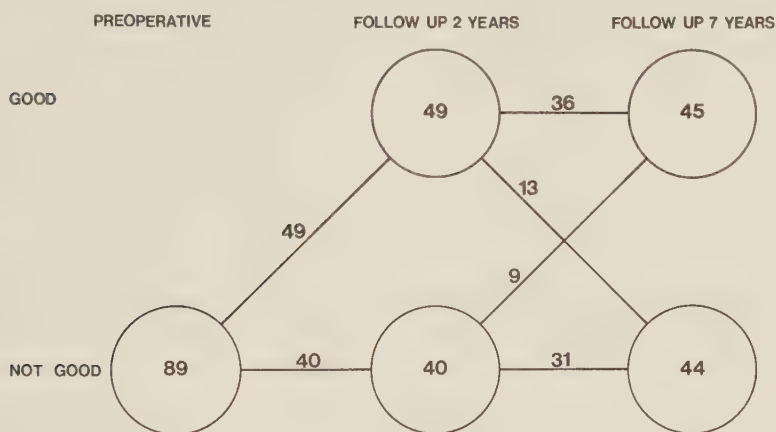


Fig. 3. Clinical result at two and seven years after osteotomy for correction of varus deformity in medial gonarthrosis. The figures refer to the number of knees.

Clinical outcome at 2 and 7 years (Fig. 3). Most of the knees which were good at the two year follow-up were good also at seven years, and in particular those which were fully corrected. Of the 36 knees that stayed good 15 were fully corrected and of the 13 knees which deteriorated only two were fully corrected. Of the nine improved knees two were fully corrected.

Effect of the osteotomy on the arthrotic process (Table 2). Further progress of the medial arthrosis had occurred in two of the 24 corrected or over-corrected knees and in two thirds (44/65) of the under-corrected knees. Seven knees had even moved to a lower stage of arthrosis; six of these were corrected and one under-corrected.

Despite the increased load on the lateral compartment of the over-corrected knees, degenerative changes were seen in only three. These had an incipient Stage I lateral arthrosis, i.e. slight narrowing of the joint space, but this did not seem to have any clinical effect.

Table 2. Change in severity of medial gonarthrosis 7 years after tibial osteotomy.

Change in severity	Under-corrected	Corrected/Over-corrected
- 1	1	6
0	20	16
+ 1	27	2
+ 2	7	
+ 3	1	
+ 4	1	
Sum	57	24

The increase in severity of arthrosis was expressed as a change from one stage of arthrosis to another.

Patellar arthrosis and pyrophosphate arthritis. Patellar arthrosis did not seem to influence the clinical outcome. Three knees had pyrophosphate arthritis and one of these was not good.

Second and third prospective series (II, III)

Precision of the operation. Of the first 66 knees, 54 were corrected within $\pm 3^\circ$ at the first postoperative control, and 45 of the knees were within this interval at the one year follow-up. Of those outside this interval, 18 knees had a loss of correction and three knees had increased correction.

In the over-correction series 44 of the 52 knees were initially within $\pm 3^\circ$ of the aimed correction. One year later, 35 knees were within this interval and another 12 were within $\pm 4^\circ$. 35 knees showed loss of correction and nine showed increased correction during the healing period. A change of correction 4° or less occurred in 44 knees during this period.

Correction of the mechanical axis (II). The knees which were corrected or over-corrected had a mechanical axis transecting the center or falling laterally through the joint. Forty-eight of the 52 knees were in this category at the one year follow-up. Three were clearly under-corrected; one knee with 1° of varus deviation was included in the corrected group.

Complications (III). In the 52 knees there were 10 complications of which three needed further operation. One septic arthritis was treated with antibiotics, drainage of the joint and extraction of the staple. One wound infection needed staple extraction before healing occurred. Two superficial infections healed with antibiotics. Two peroneal palsies recovered completely, one spontaneously and one after the nerve had been explored and released. Two cases of deep venous thrombosis required anticoagulant therapy. In one knee there was a fracture of the proximal fragment without displacement which healed without change of the postoperative standard regime.

Clinical findings (III). The range of movement did not decrease after the osteotomy, and knees which were previously unstable became stable. Of the 49 corrected or over-corrected knees 40 were satisfactory (mobile, stable and pain-free) (Fig. 4) and 45 were good (mobile, stable and pain relief). Forty-six of these knees were acceptable according to the London Hospital scoring system (Freeman et al. 1977) and 47 knees scored over 70 points in the Hospital for Special Surgery evaluation system (Ranawat et al. 1976).

Roentgen stereophotogrammetry (IV)

The roentgen stereophotogrammetric analysis revealed that the osteotomy caused angular and translational movements in all three planes, also in those where correction was not intended. A forward rotation of the distal segment was found in all cases studied. Compression of up to 3 mm along the longitudinal axis during the postoperative course occurred in all cases.

Significant movement between the segments were recorded after plaster removal, but most of the changes in correction occurred during the first three postoperative weeks.

RESULTS AFTER TIBIAL OSTEOTOMY WITH OVERCORRECTION IN MEDIAL GONARTHROSIS

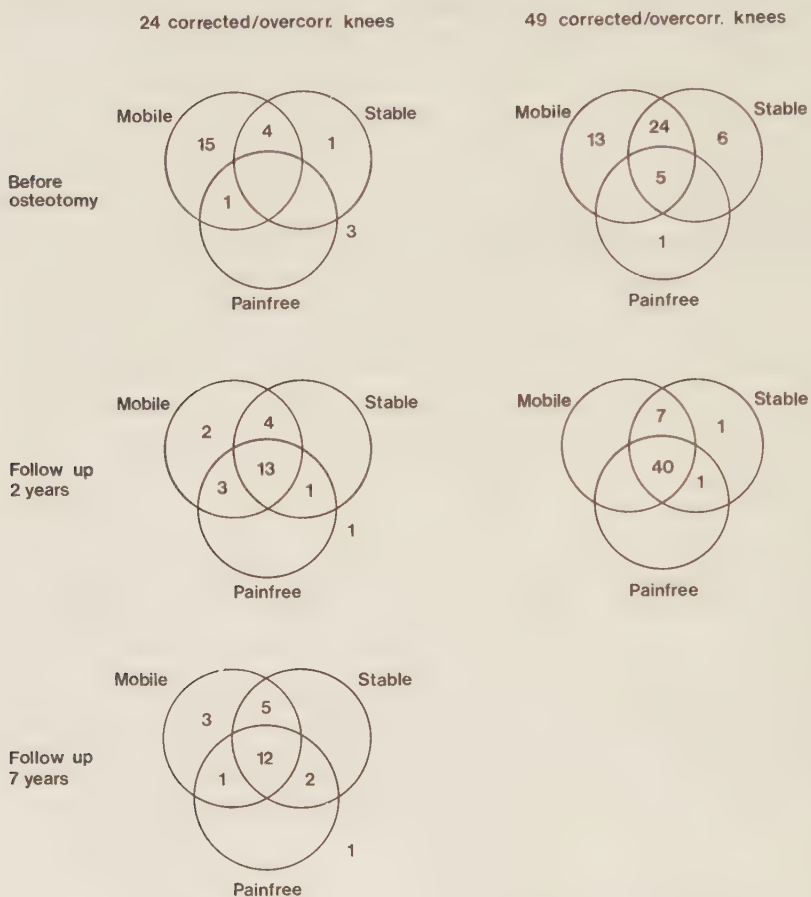


Fig. 4. Comparison of two series of knees operated on by tibial osteotomy for medial gonarthrosis and where the mechanical axis had become normal or over-corrected. The 24 knees of the first prospective series (I) were followed for more than seven years and had the same results at the two and seven year follow-up. In the third prospective series (III), the clinical results at follow-up were better with 41 pain-free knees out of 49.

The correlation between the stereo values and the conventional radiographic measurements was best in the frontal plane with a root mean square value of discrepancy of 1.3° . In the sagittal plane this value was 4.0° . These values represented the accuracy of the radiographic measurements.

Surgery for pseudarthrosis after osteotomy (V)

Out of the 12 cases with pseudarthrosis, four had non-union after another osteotomy for loss of correction, two of them below the tibial tubercle. Union was achieved in 7 out of 8 cases when the Charnley compression device was used. In the 8th knee a Guépar hinge endoprosthesis was finally used, and this was also used as the primary revision procedure in one case. Two knees were treated with the AO-compression angle blade plate and one knee was stabilized with a Blount staple. One year after the last pseudarthrosis operation all but two knees were free from pain. - Now, five years later, both endoprostheses have been removed because of infection and the knees have been arthrodesed.

GENERAL DISCUSSION

The last ten years of increasingly active surgery for gonarthrosis are now ripening toward a critical analysis of methods and indications. In the 1960's only osteotomy was available and in the 1970's a rapid succession of prosthetic designs held out the promise of success where earlier methods have failed. The experience gained over these years should yield more stringent definitions of the restrictions of different methods in terms of operative technique and patient selection.

The series presented here define some subsets of gonarthrosis where an accurate and safe method of high tibial osteotomy should be the method of choice and others where alternative methods, notably arthroplasty, should be preferred.

Method of osteotomy

The majority of osteotomies for correction of deformity in femoro-tibial arthrosis are performed immediately proximal to the insertion of the patellar tendon to the tibial tubercle. In as much as the operation is performed to correct the mechanical axis or weight-bearing angle of the knee, there are no compelling mechanical reasons to do the operation at this level. The correction could equally well be achieved by an osteotomy in the femur or in the tibial diaphysis. However, the proximal tibial metaphysis is chosen for the osteotomy because this site provides large surfaces of cancellous bone which give stability and have excellent healing potential. In fact, Bauer et al. (1969) did not use any internal fixation whatsoever, and all cases in the present investigation were allowed to bear full weight on the day after the operation. We now regularly use the Coventry (1965) staple because it probably diminishes the risk of loss of position. Some authors have used a blade plate or transfixation to stabilize the osteotomy but these methods probably carry a higher risk of complication, notably infection and peroneal palsy. Theoretically, plaster fixation for six weeks could cause stiffness of the knee with limitation of flexion. However, experience from

similar treatment of tibial shaft fractures (Edwards 1964), the osteotomy series published by Coventry (1965), Bauer et al. (1969), Hagstedt (1974), Myrnerets (1979), and those discussed here have shown that at least the pre-operative range of movement is usually regained without the aid of manipulation.

Preoperative radiographic analysis

Jackson (1958) simply tried to "make the leg look straight". However, further experience has shown that the clinical result is correlated to the precise correction of the deformity which in turn is difficult to achieve with reasonable accuracy unless the osteotomy is based on preoperative radiographic measurements.

Already in 1949 de Sèze and Coliez examined their patients radiographically in the weight-bearing position to diagnose gonarthrosis. Ahlbäck (1968) used this technique in his analysis of types, degree and development of gonarthrosis, and Bauer et al. (1969) used Ahlbäck's methods in their pre- and postoperative analysis of gonarthrosis. Hagstedt (1974) used standing stressed knee radiographs (Norman 1974) to evaluate the stage of arthrosis in both compartments.

The importance of using radiographs of the knee in standing position for calculation of the osteotomy wedge was pointed out by de Marchin et al. (1963). Maquet et al. (1967) and Ramadier (1967) have stressed the importance of using whole limb radiographs for the calculation but until recently no standardized method for these examinations has been described. Edholm et al. (1977) reported on a three-point "orthodiagraphic" method where knee joint laxity and deformity were measured in supine position.

We have chosen the biostatic knee model of Maquet et al. (1967) but also defined the frontal plane (II) which permits us to make exact comparable reexamination. This method also allowed for more precise correction (II,III).

Optimal correction

The questions are first, what is the optimal direction of the mechanical axis and second, how to achieve this. In this investigation (I) the majority of those cases which were under-corrected by more than 2° of varus or over-corrected by more than 10° of valgus were not good; the majority of those within these limits were good. The limits include the $3^{\circ} - 5^{\circ}$ of valgus deviation from the mechanical axis suggested by Maquet (1976) and Kettelkamp et al. (1976) for optimal correction. An FT-angle of 174° corresponds to the neutral position of the mechanical axis and thus the midpoint of our limits should correspond to an FT-angle of 170° , which is the optimal correction proposed by Coventry (1979) and Koshino and Tsuchiya (1979).

However, in the past many osteotomies have failed to reach this optimal correction. Under-correction (FT-angle more than 174°) in knees with medial arthrosis was found in one fourth and more than one third in the series of Bauer et al. (1969) and Hagstedt (1974), respectively. The reasons for over- and under-correction are (1) inadequate initial correction by removal of the wrong size of wedge or lack of apposition of the osteotomy surfaces, (2) a change of position in the osteotomy during the healing period, and (3) ligamentous laxity (III). The first of these sources of error can be overcome by surgical precision but the second seems unavoidable. The majority of the knees in the second and third prospective series lost correction during the healing period (II, III). This is the reason why 4° of over-correction was aimed at in the third prospective series (III); in 49 of 52 knees the mechanical axis finally lay through the center or the lateral part of the knee.

As regards ligamentous laxity, Myrnerets (1979) has demonstrated that gonarthrosis is always associated with instability but his mean value of 5.5° in 99 cases was not much higher than the 4.6° he observed in 48 healthy knees. Hagstedt (1974) found laxity to be a problem only when it was associated with subluxation of the knee. In this prospective series, medial arthrosis up to Stage III was not associated with any severe laxity because postoperatively all the knees were stable on weight-bearing. With the possible exception of arthrosis secondary to ligamentous injury or disease and

the effects of excessive over-correction (III), laxity does not seem to present a serious problem for osteotomy used for medial femoro-tibial arthrosis.

Complications

Even though the operation is carried out close to the knee joint and major vessels and nerves, high tibial osteotomy is a safe procedure. Few arterial injuries have been reported and the incidence of pulmonary embolism is low; Bauer et al. (1969) and Hagstedt (1974) reported 3 % thrombo-embolism with no fatal cases. In 419 osteotomies performed for gonarthrosis at this department 1969-80 fatal thrombo-embolism has not occurred and we have not had any arterial complications. All our cases have been operated under a tourniquet.

Less serious complications do occur however, notably peroneal palsy, non-union and infection. The incidence of peroneal palsy is about 10 % (Hagstedt 1974, Beltrami et al. 1976, McIntosh and Welsh 1977), but most cases recover spontaneously in 2-4 months; we had two peroneal palsies in the last 52 knees, and both have recovered, one spontaneously and one after surgical release. The cause of these palsies is probably postoperative hematoma; we have observed several cases which have developed peroneal palsy during the first postoperative week following normal function immediately after the operation.

Non-union has been reported in 3-4 % (Hagstedt 1974, McIntosh and Welsh 1977), but this risk will diminish as the operative technique is improved; we have had no non-unions over the last five years. If established, the condition responds favourably to active treatment; 7 out of 8 cases in this series treated with a compression device healed uneventfully (V). Two cases treated with a hinge prosthesis did well during the first couple of years but both have now been arthrodesed.

The over-all infection rate is less than 10 % (Hagstedt 1974, McIntosh and Welsh 1977, Coventry 1979, Myrnerets 1979). However, few of the infections are deep, and most authors agree that antibiotic cover for the operation is not required.

Clinical assessment

Application in this investigation of different systems for assessment of function before and after knee surgery revealed certain problems specific to the treatment of gonarthrosis. The Hospital for Special Surgery (HSS) method was too generous for the knees in this series. At the 7-year follow-up (1) we found by our definitions that 45 were mobile, stable and had had pain relief ("good") and 35 of these were pain-free ("satisfactory"). However, as many as 55 of the 89 knees had scores defined as good or excellent by the HSS system (Fig. 5). The explanation for this difference is that the HSS system gives high marks to a normal range of movement. This may be indicated in rheumatoid arthritis but definitely not in arthrosis. The range of movement is rarely a serious problem in even the most severe cases of gonarthrosis. Clearly arthrosis and rheumatoid arthritis of the knee pose such different problems that one and the same assessment cannot be useful to both.

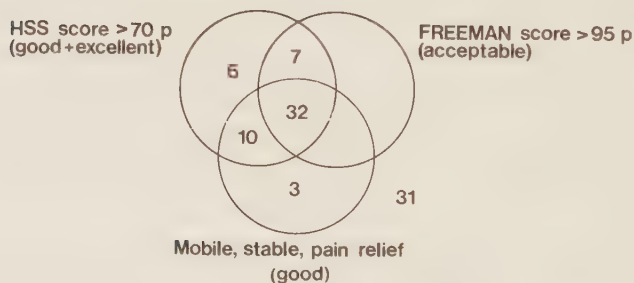


Fig. 5. Comparison of the evaluation of 89 knees with medial arthrosis rated according to the scores of the Hospital for Special Surgery system, the London Hospital system and our own Venn-diagram. Two thirds of our patients have the same rating in all systems with 32 good and 31 poor results. The HSS score with 55 good - excellent knees is more generous than our system and the London Hospital system would suggest.

Thus, as the osteotomy is applied to mild cases of gonarthrosis with the hope of preventing further progress of the disease the definitions of success suitable for more severe cases no longer apply. For example, of those 49 knees in our third prospective series (III) which had their mechanical axis corrected or over-corrected, 29 were mobile and stable before the operation and five of these were even pain-free. In this type of knee, the object of the operation is to maintain rather than to improve the function of the knee, and conventional methods of assessment of the operation no longer apply. We believe that the immediate effect of the operation should be expressed in terms of the position of the mechanical axis.

Factors which influence the effect of tibial osteotomy for gonarthrosis

Severity of arthrosis, advanced age, co-existing patellar arthrosis, pyrophosphate synovitis and ligamentous laxity are reported to have a negative influence on knee function after tibial osteotomy.

With increasing severity of arthrosis the varus deformity increases and secondary arthrosis develops in the opposite lateral compartment. Hagstedt (1974) had a high incidence of under-correction in Stage IV and V arthrosis and at the 7-year follow-up of his material these cases were not as good as those operated on at an earlier stage of the disease; it is easier to correct 10° than 20° by wedge osteotomy.

Advanced age does not in itself contraindicate an osteotomy, but gonarthrosis progresses with age. Previous reports which blame advanced age for poor results may have failed to note a higher incidence of advanced cases in the oldest patients. However, rehabilitation following osteotomy is a lengthy procedure, usually six months or even more, and we feel this is psychologically too much for the elderly. The period of social isolation is shorter after an arthroplasty than after an osteotomy, and this is the reason why we put 65 years as the upper limit in our prospective series.

Co-existing patellar arthrosis is not a contraindication to osteotomy for medial femoro-tibial arthrosis according to Insall et al. (1974) and Goutaillier et al. (1979), and they have described some cases of improved patellar function after the operation. These opinions also agree with Hagstedt (1974) and with the findings in our seven year follow-up. Even though our third prospective series (III) contained more knees with patellar problems in the unsatisfactory group, Jónsson's (1981) observation that patellar arthrosis rarely poses a problem in unicompartmental arthroplasty for gonarthrosis confirms our policy to disregard patellar problems in the treatment of femoro-tibial arthrosis. At any rate, patellectomy should definitely not be performed in conjunction with tibial osteotomy for gonarthrosis; the worst results following unicompartmental arthroplasty for gonarthrosis were reported by Insall and Aglietti (1980) in a series in which one half had had patellectomy.

Pyrophosphate synovitis, on the other hand, seems to contraindicate both osteotomy and unicompartmental arthroplasty (Coventry 1979, Jónsson 1981). We had three cases following osteotomy which were complicated by pyrophosphate arthritis (I, III).

Ligamentous laxity, secondary to primary femoro-tibial arthrosis, rarely seems to create a problem following osteotomy provided the mechanical axis has been fully corrected. Subluxation under weight-bearing disappears when the mechanical axis has been corrected (Egund 1981). However, when bony over-correction has occurred, laxity may contribute to overloading of the opposite compartment with inferior results (I, III).

Effect of the osteotomy on the articular cartilage

Hernborg and Nilsson (1978) showed that gonarthrosis is a progressive disease; the majority of knees followed for an average of 15 years had severe loss of cartilage and bone. In this series of knees followed for seven years the osteotomy had delayed or even prevented this progressive course. Among the 24 corrected or over-corrected knees two had deteriorated by one stage, 16 had stayed at the same stage, and in six cases the degree of arthrosis had

diminished so that there were definite radiographic signs of improvement of the articular cartilage. In contrast, one third of the under-corrected knees showed some progression of the disease, and only one knee in this group had improved radiographically. Also in the subsequent series some cases had definite radiographic regression of the arthrotic condition in as short a time as one year after the osteotomy. Radiographic signs of improvement of the articular cartilage following hip surgery for arthrosis have been observed by Robins et al. (1960), Salenius et al. (1971), Collert (1974) and Radin et al. (1975) but have often been dismissed as positional effects on the radiographs. However, Maquet (1976, 1980) has reported cases of gonarthrosis which after osteotomy have shown a widened joint space as evidence of cartilage regeneration and a reduction of subchondral sclerosis as an effect of diminished articular load. Coventry (1979) and Koshino and Tsuchiya (1979) have demonstrated an improvement in the articular cartilage by autopsy and biopsy observations. Recent arthroscopic studies (Fujisawa et al. 1979 and Matsui et al. 1979) confirm these findings. The credibility of these clinical findings is supported by experimental observations of articular cartilage regeneration in arthrotic lesions (Hulth et al. 1970, 1972, Mankin 1977).

We have not observed much effect of an increased load on the articular cartilage in the lateral compartment following osteotomy for medial femoro-tibial arthrosis. A decrease in the lateral joint space was observed radiographically in only three of the 24 corrected or over-corrected knees followed for seven years and in only one of the 49 corrected knees in the third prospective series. None of these four cases had any clinical problems related to degeneration of the lateral compartment. Our observations which agree with those of Coventry (1979) are encouraging in view of the report by Laskin (1978) that several knees had developed lateral arthrosis after unicompartmental arthroplasty for medial femoro-tibial arthrosis. However, the author did not document his findings, and Jónsson (1981) could not confirm these alarming observations in arthrosis Stage I-III in his considerably longer series of unicompartmental arthroplasty.

Further surgery after failed osteotomy for gonarthrosis

Non-union, under-correction and associated lateral arthrosis are well known causes of failure after osteotomy for medial gonarthrosis. In some cases, no obvious cause of failure can be identified. In most cases of failed osteotomy for gonarthrosis adequate knee function can usually be restored with the aid of other procedures. In this sense the tibial osteotomy is less dangerous than arthroplasty as a primary procedure in gonarthrosis.

In established non-union healing usually occurs with the aid of an external compression device (V). Under-correction requires a re-osteotomy. Hagstedt (1974) did not report any technical difficulties in 26 reoperations for loss of correction apart from a higher incidence of non-union (V). In the elderly, however, repeat osteotomy for under-correction makes the rehabilitation period unreasonably long, and a prosthetic arthroplasty may well be a better solution.

Jónsson (1981) had 11 satisfactory results in 15 cases of medial Marmor uni-compartmental arthroplasty after failed tibial osteotomy. The 4 failures were not related to previous osteotomy. If the lateral compartment is also involved in the arthrotic process, common in Stage IV and V medial arthrosis with subluxation, we have used a total condylar prosthesis (Insall et al. 1979). In the past we have used the Guépar hinge prosthesis for salvage but two cases of persisting non-union finally required arthrodesis (V). The experience with the hinge prosthesis in a Swedish multi-center investigation has been very poor (Bauer et al. 1980).

The future

Hernborg and Nilsson (1977) have demonstrated the progressive course of gonarthrosis. In their series of untreated cases, with a mean age of 63 years in 1955, few had severe bone attrition and two thirds had cartilage loss only. 15 years later one third had severe bone attrition and most had significantly impaired knee function. Today, the operative treatment for gonarthrosis is well documented. On the basis of the choice between tibial osteotomy

and prosthetic replacement proposed here (I, III Jónsson 1981, Bauer 1981) the majority of Hernborg and Nilsson's (1977) patients should have had an osteotomy in 1955 and an arthroplasty in 1968.

In the series of Hagstedt (1974), many cases had a long previous history of knee pain and even the most severe cases had an osteotomy because arthroplasty for gonarthrosis was not introduced until later. If our present indications were applied to this series, 40 % should have had an osteotomy (age below 65 years, medial type arthrosis Stage I-III). Of the remaining knees 40 % and 20 % should have had uni- or tricompartment resurfacing respectively, because of lateral or advanced arthrosis or age.

Today (Fig. 1) one fourth of the operations are osteotomies, but the arthroplasty fraction includes revision procedures of failed osteotomies and other prostheses. Nowadays, osteotomies are seldom under-corrected (III), and the surgical technique of prosthetic arthroplasty has improved (Jónsson 1981). The proportion of tibial osteotomy should therefore increase to 0.4 based on the patients of Hagstedt (1974) and to 0.8 based on the original cases of Hernborg (1977).

Our observations (I, III) and the above speculations indicate that high tibial osteotomy should be the treatment of choice in early medial gonarthrosis. The decrease in our use of this procedure over the last five years has had a logic explanation and should revert to an increase (Bauer et al. 1982). The patient who has had a technically precise osteotomy at the correct stage in the development of arthrosis of the knee should have no need for further operation in the future ...

GENERAL SUMMARY

The purpose of this investigation was to evaluate the long term effect of tibial osteotomy on pain, function and the state of the articular cartilage, to evaluate the treatment of non-union of the osteotomy, and to increase the accuracy of correction by improved preoperative radiographic examination and surgical precision.

In a series of 107 osteotomies followed-up for more than seven years the medial type arthrosis had better results than the lateral type. Of 89 knees with medial arthrosis those which were corrected or over-corrected gave the best results. Severe arthrosis was more difficult to correct and gave also inferior results. The osteotomy arrested further progress of the arthrosis in the corrected group and in some cases there were signs of cartilage regeneration. The increased load in the lateral compartment did not bring any disadvantages.

Twelve cases with non-union after tibial osteotomy required further operation. In the majority an external compression device was used. Other procedures involved compression blade plate fixation and arthroplasty with a hinge prosthesis. All eventually healed, but the arthroplasty cases eventually required arthrodesis because of infection.

A new preoperative radiographic routine with standardized exposures and exact calculation of the wedge together with improved surgical technique gave more precise correction in 66 knees. The loss of correction for the majority was less than 4° .

Using this routine in early medial gonarthrosis and aiming at over-correction of the mechanical axis into valgus 52 knees were operated upon and 49 of these were corrected or over-corrected. The clinical outcome for these knees was good.

The movement of the osteotomy was studied by roentgen stereophotogrammetry in three knees. Measurements revealed that the osteotomy allowed

movement in planes where correction was not intended and that complete stability was not present when the knee mobilisation started. The accuracy of radiographic measurements was calculated and was best in the frontal plane, about 1° . This is adequate for clinical use.

It is concluded that the long-term prognosis in medial femoro-tibial arthrosis is good following tibial osteotomy provided the mechanical axis has been adequately corrected. Present radiographic and surgical methods permit adequate correction in 90 % of cases operated before attrition of bone has caused subluxation with arthrosis in the opposite compartment. Arthroplasty for gonarthrosis would then be reserved for the minority of patients with failed osteotomies, lateral and bicompartamental arthrosis, massive osteonecrosis and advanced age. Based on the analysis of previously published series of gonarthrosis the proportion in the future of osteotomy versus arthroplasty for gonarthrosis may well approach 3/1 as compared to our present ratio of 1/3.

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HIGH TIBIAL OSTEOTOMY

A seven year clinical and radiographic follow-up

by

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INTRODUCTION

Initial favourable outcome of high tibial osteotomy for gonarthrosis is well documented, in particular in medial type arthrosis without severe deformity. Since there still are doubts concerning the long term results of tibial osteotomy we have re-examined the Hagstedt (1974) series of knees, now seven years after operation. We report here on the clinical findings and radiographic development in the different compartments of the knee correlated to the correction derived from the osteotomy.

MATERIAL

Base material. At the Department of Orthopaedic Surgery in Lund 178 high tibial osteotomies for femuro-tibial arthrosis were performed during the years 1969-1971. Rheumatoid arthritis was excluded from this material. Hagstedt (1974) examined 166 of these knees at least two years after the operation which was performed as a closing wedge osteotomy in the majority of the cases. Two thirds of the knees had been corrected to a femuro-tibial weight-bearing angle $174^{\pm 6^{\circ}}$ and three fourths of these corrected cases were improved clinically.

Present material. Five to six years later, i.e. at least seven years after the tibial osteotomy, we have re-examined 107 knees in 99 patients. Thirty-four patients had died (34 knees) and 19 could not participate because of senility or other disease or change of location (25 knees). The group of not re-examined knees did not differ appreciably from the 107 re-examined as regards type and degree of arthrosis, but the dead patients' mean age at the time of operation was 70 years compared to 65 years for the follow-up group.

At the time of operation 89 knees had medial type arthrosis and 13 of these also had radiographic signs of patellar arthrosis; 18 knees had lateral arthrosis and four of these had patellar arthrosis.



Fig. 1a.



Fig. 1b.

Fig. 1. Preoperative and eight years follow-up roentgenograms of both knees, stressed in varus (Fig. 1a, 1c; note the pillow between the knees) and valgus (Fig. 1b, 1d). This patient is a woman 51 years old at the time of operation and had a previous history of weight-bearing pain from the first step for several years. Eight years after the osteotomy she was free of symptoms and was still working. The roentgenograms now showed no further progress of the arthrosis and revealed a joint space medially indicating Stage I arthrosis (Fig. 1c) and intact cartilage laterally (Fig. 1d).

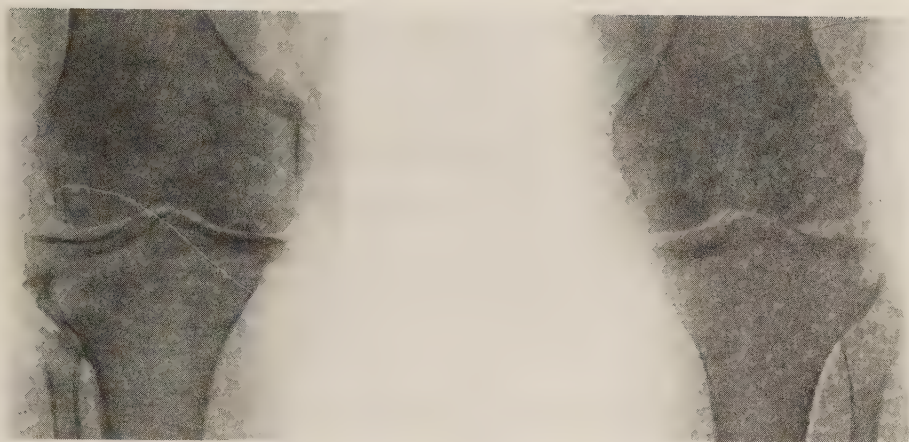


Fig. 1c.

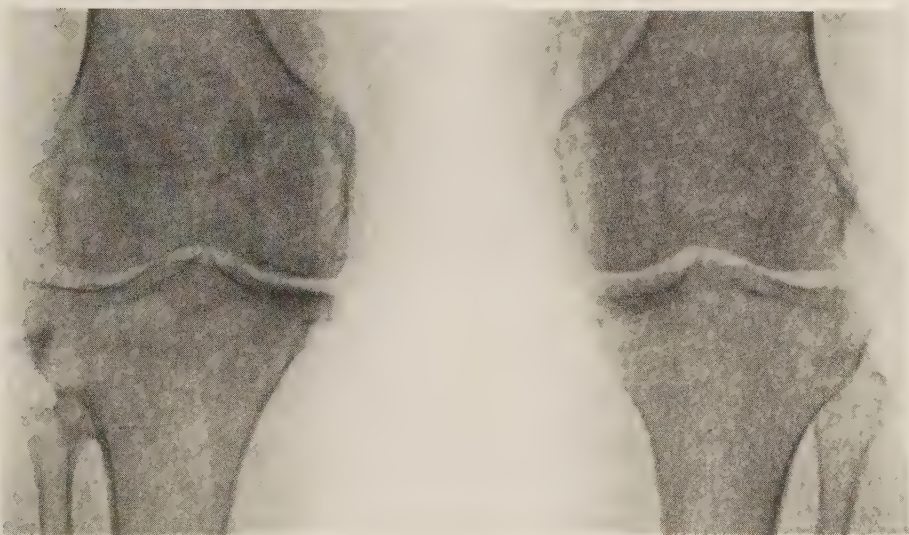


Fig. 1d.

EXAMINATION METHODS

Clinical examination

Mobility. A knee with a range of motion more than 90° and an extension defect not more than 5° was considered mobile.

Stability. A knee without signs of lateral or medial thrust on walking was considered stable (Bauer et al. 1969, Hagstedt 1974).

Pain. Pain was recorded both as the pain-free walking distance and as pain at rest, only after exercise or spontaneous. In our evaluation of pain we used the relative concept pain relief for knees which permitted a pain-free walking distance more than 100 meters and in which this distance had increased as compared to preoperatively.

Assessment system. To classify the knee function we used the three parameters of mobility, stability and pain-free in a Venn-diagram according to Bauer et al. (1969) and Hagstedt (1974). They used consumption of analgesics to distinguish between pain-free or not. We have preferred the stricter definitions above and applied the term good to knees which were mobile, stable and had pain relief.

Radiographic examination

The examination method used preoperatively for classification of arthrosis was used also at the two and seven year follow-ups. In addition the mechanical axis of the knee was determined at the seven year follow-up; this examination gave more precise information than the femuro-tibial angle determined preoperatively and at the two year follow-up (Egund et al. 1979, Hagstedt et al. 1980).

Classification. Frontal projections of knees stressed in valgus and varus with the patient standing provided the basis for definition of type and degree of arthrosis (Fig. 1). A distinction was made between medial and lateral femuro-tibial arthrosis, and each type was classified in five stages (Ahlbäck 1968)

from merely narrowing of the joint space to severe bone attrition with subluxation and often secondary changes in the opposite compartment (Table 1).

Table 1. Stage of medial gonarthrosis before osteotomy and at seven year follow-up.

Stage of gonarthrosis (Ahlbäck 1968)		Before operation	Follow-up	Further surgery
I	Narrowing of joint space	18	12	
II	Obliteration of joint space	19	10	
III	Minor bone attrition	34	28	
IV	Moderate bone attrition	8	18	
V	Major bone attrition, often with subluxation and second- ary lateral arthrosis	10	13	
Sum		89	81	8

Mechanical axis. In order to determine the mechanical axis of the knee, frontal projections were obtained of the whole leg weight-bearing (Egund et al. 1979, Hagstedt et al. 1980). The mechanical axis was defined as the line between the centres of the femoral head and the talo-crural joint (Fig. 2) (Maquet 1976, Maquet et al. 1967). In medial arthrosis under-correction was recognized when this axis transected the knee joint medial to the intercondylar notch. Conversely, under-correction in lateral arthrosis caused the mechanical axis to fall laterally. The deviation of the mechanical axis was measured as the angle between the lines from the intercondylar notch to the centres of the femoral head and the talo-crural joint, respectively.

Statistical analysis

Chi-square test with Yates' correction was used.



Fig. 2. Whole leg roentgenogram to determine the mechanical axis. The frontal plane is defined (Hagstedt et al. 1980) and the central ray passes through the centre of the knee. The deviation angle was measured between the lines from the tibial eminence to the centres of the femoral head and the talo-crural joint, respectively. This case has an over-correction of 4° following high tibial osteotomy for correction of Stage II medial gonarthrosis.

RESULTS

The results are presented here separately for medial and lateral arthrosis.

Medial arthrosis

Eighty-nine knees had medial arthrosis (Table 2). Eight of these had further surgery and of the remaining 81 knees 45 were good and 36 were not. The results presented here concern mainly those 81 knees.

Further surgery. Since the two year follow-up eight knees with medial arthrosis had undergone further surgery because of impaired knee function; at the two year follow-up none of these knees had achieved the aimed correction. Now one had an arthrodesis, one a hinge prosthesis, one a bicompartamental endoprosthesis and five had unicompartmental endoprostheses (Jónsson 1981). All but one of the re-operated knees had Stage III arthrosis or worse at the time of osteotomy.

Pain. Thirty-one of the 81 knees had no pain at rest preoperatively compared with 55 knees at seven years ($p < 0.001$). Continuous pain at rest was reported for 19 knees preoperatively and for five knees at seven years; one of these knees was corrected and four were under-corrected. Impairment of pain at rest from the two year to the seven year follow-up was reported for three corrected knees and eleven under-corrected knees.

Increased pain-free walking distance was found in 61 knees. Twenty-three of these were in the corrected group of 24 knees and 38 were in the under-corrected group of 65 knees including the eight re-operated knees ($p < 0.001$). Twenty knees were unchanged or had diminished pain-free walking distance; one of these was corrected and the other 19 under-corrected (Fig. 3).

Mobility. Preoperatively 66 knees had a range of motion more than 90° and at seven years 73 knees. No difference in loss of motion was noted between corrected and under-corrected knees, nor between those relieved of pain and those not.

Table 2. Outcome 7 years after tibial osteotomy for medial gonarthrosis.
N:89.

Stage of arthrosis		Outcome at 7 year follow-up			
Before operation	7 years follow-up	Good		Not good	
		Corrected	Not corrected	Corrected	Not corrected
I	I	3	2	1 (1*)	
	II	1	4		1 (1*)
	III		3		2 (1*)
	IV				
	V				1 (1*)
II	I	3 (1*)			1
	II	2		1	
	III	1	4		1
	IV				1
	V				1
III	reop				1
	I	1			
	II	1 (1*)			
	III	2	6	3 (1*)	3
	IV		4		9 (2*)
IV	V				1 (1*)
	reop				4
	I			1	
	II				
	III				
V	IV	1	1		2
	V		1		
	reop				2
	V	2 (2*)	3	1	3 (1*)
	reop				1

The outcome for all 89 knees is specified here as a preoperative and a final stage of arthrosis, effect of the operation on deviation angle (corrected or not) and clinical result (good or not). Cases that had further surgery were classified as not good. (*stands for co-existing patellar arthrosis).

PAIN-FREE WALKING DISTANCE IN MEDIAL GONARTHROSIS

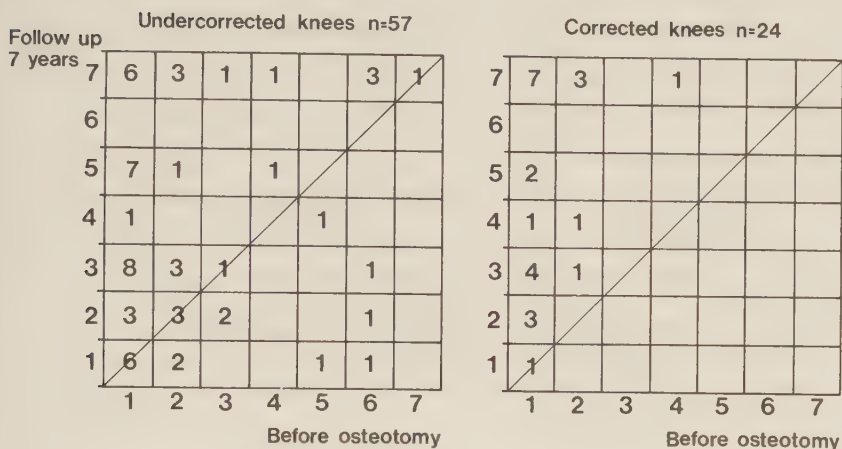


Fig. 3. Pain-free walking distance was categorized as following (1) pain from the first step; (2) less than 100 meters; (3) 100-500 meters; (4) 500-1000 meters; (5) more than 1000 meters; (6) only starting pain; (7) no pain on walking.

Stability. Before the osteotomy 15 knees were stable and at seven years 60 knees ($p < 0.001$). No difference in stability was found between corrected and under-corrected knees.

Correction. At the seven year follow-up there was wide variation around the ideal mechanical axis transecting the centre of the knee (Fig. 4). Deviation in varus was found in 57 knees and of those 28 had good results. In 18 knees the deviation was more than 10° of varus and only three of them were good ($p < 0.001$). Correction and over-correction in valgus showed better clinical results. Of 24 knees in this group 17 had good results ($p < 0.001$). Six knees were over-corrected more than 10° of valgus and two of them had good results (NS). The best results were seen in the interval from no deviation of the mechanical axis to 10° of valgus where only two of 17 were not good ($p < 0.001$) (Table 3).

CORRECTION IN MEDIAL GONARTHROSIS 7 YEARS AFTER OSTEOTOMY
N:81

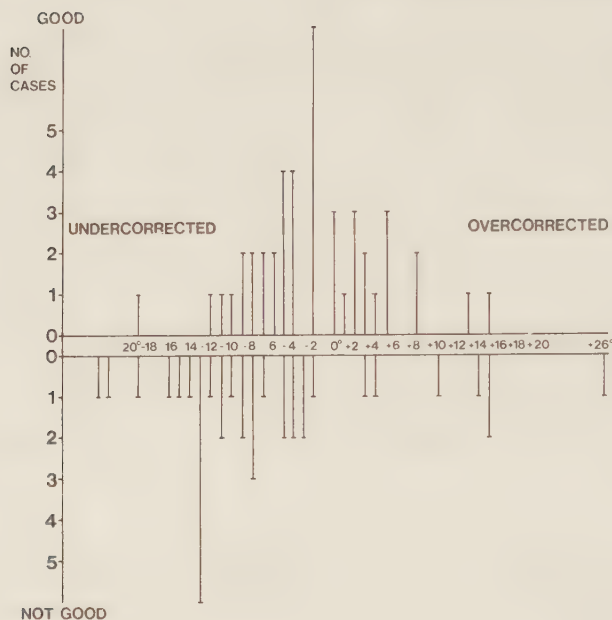


Fig. 4. Deviation of the mechanical axis of the knee seven years or more after high tibial osteotomy for correction of medial gonarthrosis. 0° stands for the axis transecting the tibial eminence.

Table 3. Outcome in different intervals of correction seven years after tibial osteotomy. N:81.

Deviation of mechanical axis	$\leq -10^{\circ}$	$-9^{\circ} - -3^{\circ}$	$-2^{\circ} - -1^{\circ}$	$0^{\circ} - +9^{\circ}$	$\geq +10^{\circ}$
Good	4	16	8	15	2
Significance	-	N.S.	xx ($p < 0.01$)	xxx ($p < 0.001$)	N.S.
Not good	16	12	1	2	5
Significance	xxx ($p < 0.001$)	N.S.			N.S.

Stage of arthrosis. The outcome seven years after tibial osteotomy was better in early than in late stages of arthrosis (Table 2) ($p < 0.05$). Out of 37 knees which had Stage I or II arthrosis preoperatively, 28 became good. By contrast only 25 of 52 in Stage III or more became good. Under-correction was more common in late stages; more than 5° under-correction was found in six of 36 knees in Stages I and II and in 16 of 45 knees in Stages III-V. Furthermore all knees that had had further surgery had under-correction at the two year follow-up and all but one had Stage III arthrosis or worse preoperatively. Seven years after the osteotomy further progress in the course of arthrosis had not occurred in 43 knees with medial arthrosis; seven knees had even moved to a lower stage of arthrosis (Table 2). Of 24 corrected and over-corrected knees only two deteriorated to a higher degree of arthrosis while 36 of the 57 under-corrected knees progressed by one or more stage (Table 4) ($p < 0.001$).

Table 4. Increase in severity of medial gonarthrosis seven years after tibial osteotomy.

Increase in severity	Under-corrected	Corrected
0	21	22
1	27	2
2	7	
3	1	
4	1	
Sum	57	24

The increase in severity of arthrosis was expressed as a change from one stage of arthrosis to another, see Table 1.

Lateral compartment. The opposite lateral compartment in the knees with medial gonarthrosis was found to be affected in five cases at the seven year follow-up. Three over-corrected knees had an incipient Stage I lateral arthrosis, i.e. a slight narrowing of the joint space. Two under-corrected knees had developed a secondary lateral arthrosis due to translation of the tibia laterally with collision of the lateral femoral condyle against the intercondylar eminence.

Patellar arthrosis. Of the 81 knees with medial arthrosis 13 had co-existing patellar arthrosis at the time of operation. Four of these were good versus 41 of 68 with medial arthrosis only (NS). Two of these 13 knees were found among the seven knees which were corrected and not good.

Clinical results compared after two and seven years. At the two year follow-up 49 of the 89 knees with medial arthrosis were good, i.e. they were mobile, stable and had pain relief. During the following five years 13 of these 49 knees deteriorated to become not good and nine formally not good became good. Of the 36 knees that had stayed good 15 were corrected; of the nine improved knees two were corrected; of the 13 worsened knees two were corrected. Two of these worsened knees had had further surgery (Figs. 5, 6).

MOBILITY, STABILITY AND PAIN BEFORE AND AFTER TIBIAL OSTEOTOMY
IN MEDIAL GONARTHROSIS N=89

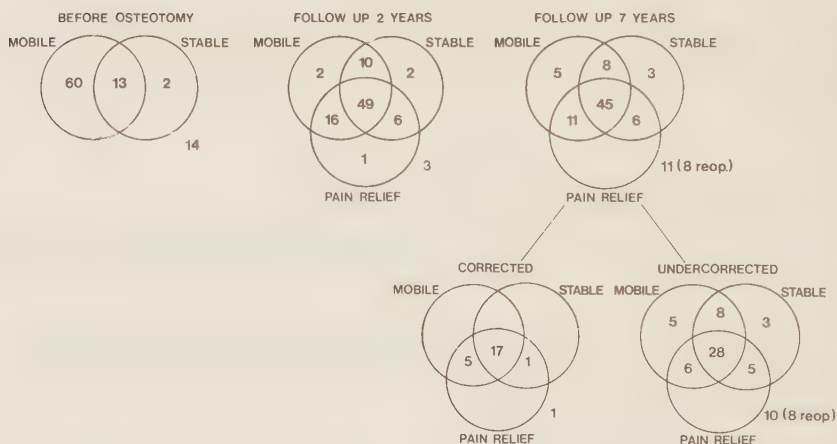


Fig. 5. Knee function before osteotomy and at the two- and seven year follow-ups. The knees that had reached the centre set of the Venn-diagram were stable, mobile and had obtained pain relief, i.e. the definition of a good result in this report.

CLINICAL RESULTS 2 AND 7 YEARS AFTER TIBIAL OSTEOTOMY
IN MEDIAL GONARTHROSIS N=89

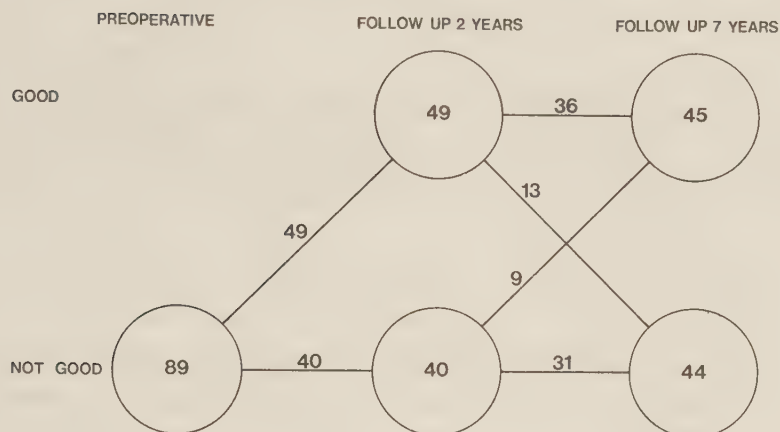


Fig. 6. Clinical result at two and seven years after osteotomy for correction of varus deformity in medial gonarthrosis. The digits show number of knees.

Lateral arthrosis

Further surgery had been performed in six of the 18 knees with lateral arthrosis. Of the remaining 12 knees six were good. Co-existing patellar arthrosis was found in four knees and of these two were good. No correlation was found between the degree of correction and final function. Progress of the arthrosis was observed in all 12 knees. Medial arthrosis had not developed in any of these.

DISCUSSION

The last 10 years of increasingly active surgery for gonarthrosis are now ripening toward a critical analysis of methods and indications. In the 1960s

only osteotomies were available, and in the 1970s a rapid succession of endoprosthesis designs held out the promise of success where earlier methods had failed. The experience gained over these years should not permit improved definitions of the restrictions of different methods in terms of both operative technique and indications.

The material presented here clearly defines some subsets of gonarthrosis where tibial osteotomy should be the method of choice and some where other methods, notably arthroplasty, should be preferred.

Lateral arthrosis

In our series only six of 18 had good results at seven years and six had had further operations. Our material confirms that high tibial osteotomy for lateral arthrosis is unpredictable; Shoji and Insall (1973) found poor results in 23 out of 49 knees. In contrast to medial gonarthrosis the distribution of good results in the lateral group was not correlated to the correction achieved. In several cases the preoperative deformity was over 20° ; it is clearly a loosing surgical proposition to correct a valgus angle of that magnitude, resulting in a tibial tilt known to be deleterious. Even though an occasional case may do well after tibial osteotomy for correction of valgus deformity in lateral gonarthrosis we now prefer arthroplasty; Laskin (1978) and Jónsson (1981) have reported good results following unicompartmental arthroplasty in this condition.

Co-existing patellar arthrosis

In the 24 cases of medial arthrosis which had been corrected six had patellar arthrosis at the time of operation. Two of these six knees were unsatisfactory at seven years compared to five out of the 18 knees without co-existing patellar arthrosis. We interpret our findings and those of others (Goutallier et al. 1979, Hagstedt 1974, Insall et al. 1974) to mean that co-existing patellar arthrosis does not contraindicate tibial osteotomy in medial gonarthrosis.

With reference to Ahlbäck (1968) and Hernborg (1978) it should be emphasized that the diagnosis of patellar arthrosis requires identification of articular cartilage destruction; absence or presence of osteophytes is of no consequence in this respect.

Medial gonarthrosis

Our results and those of others have shown that medial gonarthrosis, either primary or secondary to osteonecrosis (Bauer 1978) may well give lasting pain relief from tibial osteotomy for correction of the varus deformity. However, under-correction courts failure, and full correction is hard to achieve in the more advanced stages of the condition.

The importance of adequate correction. Under-corrected knees did poorly; 15 of 18 knees with varus over 10° were not good. Over-correction seems to be tolerated better with two good of six knees in more than 10° valgus. Along with previous authors (Coventry 1973, 1979, Jackson and Waugh 1974, Kettelkamp et al. 1976, Maquet 1976, Maquet et al. 1967, Myrnerets 1979) we strongly recommend that osteotomy in medial gonarthrosis should aim at some over-correction. Since three years we aim at 4° over-correction; Hagstedt et al. (1980) found that spontaneous loss of correction up to 4° occurred in more than half of those who were in neutral position immediately after the operation. In a current prospective series of 52 osteotomies for medial gonarthrosis we have therefore aimed at 4° over-correction. In 52 knees bony union of the osteotomy had occurred with the mechanical axis neutral or over-corrected in 48 knees (Tjörnstrand et al. 1981). This is a considerable improvement over the series published by Bauer et al. (1969) and Hagstedt (1974) but we feel this rate of success is a minimal requirement for using tibial osteotomy as preventive measure in active patients with Stage I or II arthrosis. We wish to emphasize also that a rigidly standardized technique for X-ray measurements of the mechanical axis is a prerequisite for a high success rate in tibial osteotomy.

Stage of arthrosis. It is easy to correct knees with relatively mild deformity.

Under-correction more than 5° occurred three times more often in knees with bone attrition as compared to those with only loss of cartilage. We have interpreted this correlation between correction and severity of the arthrotic process as a warning not to perform osteotomies for gonarthrosis with severe bone attrition.

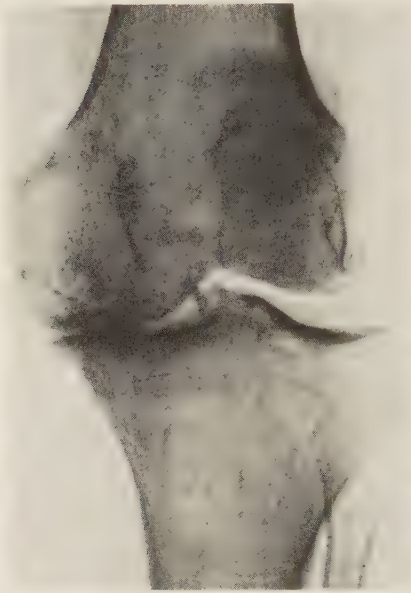


Fig. 7a.



Fig. 7b.

Fig. 7. Preoperative and eight year follow-up roentgenograms of the left knee following high tibial osteotomy for Stage II medial gonarthrosis. At the time of operation this woman was 56 years old and had had weight-bearing pain from the first step for several years. The roentgenograms show the knees stressed in varus before the osteotomy (Fig. 7a) and at the follow-up (Fig. 7b). Eight years after the operation the patient was free of symptoms, was working, and on the roentgenograms no signs of further progress of the arthrotic condition was seen; rather the appearance of a joint space in the medial compartment of the stressed knee in Fig. 7b suggests that the articular cartilage has improved.

Effect of the osteotomy on the arthrotic process. In this series the roentgenographic examination was standardized to permit comparison of the same knee at different time intervals. Unfortunately roentgenographic classification of arthrosis is rarely seen in reports of operative treatment of gonarthrosis. Here

we used a classification based on Ahlbäck (1968) and we were thus able to follow the course of development of the operated knees. When the varus deformity had been corrected further progress of the disease was rare. This means that high tibial osteotomy may interrupt the natural course of gonarthrosis (Hernborg 1978). In some cases even signs of healing were observed, i.e. roentgenographic signs of restitution of the cartilage (Figs. 7, 8). This corresponds well with findings reported by Koshino and Tsuchiya (1979), Coventry (1979) and Maquet (1976) and may perhaps confirm Mankin's (1974) observations that experimental cartilage lesions may heal provided the pathologic process has not gone too far.



Fig. 8a.

Fig. 8b.

Fig. 8. Preoperative and eight year follow-up roentgenograms of the left knee following high tibial osteotomy for Stage II medial gonarthrosis. At the time of operation this woman was 61 years old and for the last five years she had had weight-bearing pain and a maximal walking distance less than 500 meters. The roentgenograms show the knees stressed in varus before the osteotomy (Fig. 8a) and eight years after the osteotomy (Fig. 8b). No further progress in the arthrotic process and possibly even improvement to Stage I arthrosis are seen. The patient now is pain-free and has a maximal walking distance more than 1000 meters.

On the other hand the increased load on the opposite compartment of the knee does not even in the long run seem to harm the articular cartilage. It is surprising therefore that Laskin (1978) reported that over-correction in valgus after resurfacing arthroplasty of the medial compartment had caused lateral arthrosis requiring further surgery within a few years. In our 81 knees with medial gonarthrosis there were after seven years only a slight narrowing of the lateral joint space in three over-corrected knees; these three knees were all pain-free. Two under-corrected knees had secondary changes at the lateral femur condyle due to collision against the tibial eminence but these findings rather support the basic concept of the focal nature of arthrosis (Ahlbäck 1968, Bauer et al. 1969, Hagstedt 1974. Finally Jónsson (1981) in this department was unable to confirm Laskin's (1978) findings.

How good is a good knee?

Bauer et al. (1969) introduced a Venn-diagram for evaluation of knee function by integration of three parameters, mobility, stability and freedom from pain, and their definition of these parameters was used by Hagstedt (1974) in his two-year follow-up of the material which we have now followed for five more years. However, their definition of freedom from pain - not more than occasional use of analgesics - is less demanding than our definition of the concept pain relief - a pain-free walking distance of at least 100 meters and an increase in this distance as compared to preoperatively. Out of those knees which were mobile and stable at the seven-year follow-up of our 89 knees, we thus rated 45 as good because they also had pain-relief whereas an additional eight were pain-free according to the definitions of Bauer et al. (1969).

In his analysis of compartmental arthroplasty for gonarthrosis Jónsson (1980) in our department further sharpened the definition of freedom from pain by the request of a pain-free walking distance not less than 500 meters; by conjunction with mobility and stability as defined here a knee was termed satisfactory. When applied to our material, Jónsson's definition of freedom from pain was found to hide considerable improvements; 10 of our 45 good knees

with a pain-free walking distance of 100 meters or more did not permit extension of this distance to 500 meters; still we have chosen to classify these knees as good.

In a current prospective series of osteotomies for gonarthrosis from this clinic (Tjörnstrand et al. to be published) the indications for surgery were based on the results presented here; age usually less than 65 years, only medial compartment involved and at most Stage III arthrosis, i.e. minor bone attrition only. At the one-year follow-up of these 48 knees, 39 were mobile, stable and had pain relief, and those same 39 knees all had a pain-free walking distance of 500 meters or more and thus satisfied Jónssons's (1981) criteria. In as much as all of these knees had their mechanical axis corrected and that the results presented here have shown that the risk for deterioration from the one-year knee function is small indeed, we conclude that osteotomy performed early rather than late can be expected to give better knee function.

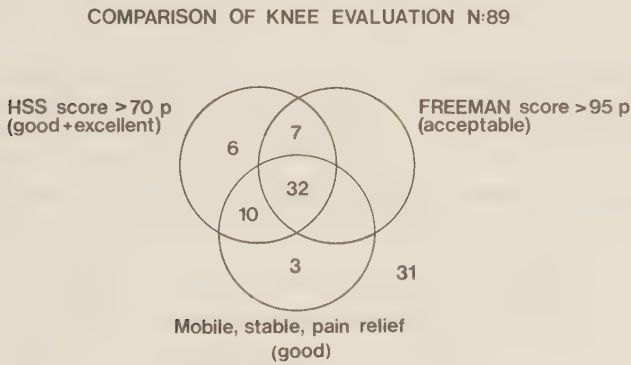


Fig. 9. Comparison of the evaluation of 89 knees with medial arthrosis rated according to the scores of Hospital for Special Surgery (Myrnerets 1979), London Hospital (Freeman et al. 1977) and our own Venn-diagram (Fig. 5). Two thirds of the knees have the same rating in all systems with 32 good and 31 poor results. The HSS score with 55 good - excellent knees is more generous than our system and the London Hospital system.

When we assessed our 89 knees according to the systems developed at the Hospital for Special Surgery (HSS) in New York (Ranawat et al. 1976) and at the London Hospital (Freeman et al. 1977) we found 55 knees good or excellent according to the former and 39 acceptable according to the latter versus 45 good by our own criteria (Fig. 9). The rather generous assessment of our results according to the HSS system reflects that this system has been developed for evaluation of knee function in both arthrosis and rheumatoid arthritis. In rheumatoid arthritis the range of motion is often restricted and the HSS system therefore allots a large fraction of the total points for normal postoperative mobility. However, in gonarthrosis mobility is rarely a problem; in our material the majority had a range of motion more than 90° already preoperatively, and postoperatively the range of motion was not significantly impaired even in under-corrected, painful knees. The HSS system therefore is not ideal for evaluation of surgery for gonarthrosis. The London Hospital system is less permissive but both these systems suffer from lack of information concerning the three basic characteristics of the knee, mobility, stability, and freedom from pain; comparison of one knee with another, or one material with another is therefore difficult.

SUMMARY

A series of 107 knees were evaluated for mobility, stability and pain relief two and seven years after high tibial osteotomy for correction of deformity secondary to arthrosis; rheumatoid arthritis was excluded from this series. There were 18 knees with lateral femuro-tibial arthrosis, only six of which were good at seven years and as many as six had had further surgery.

Eighty-nine knees had medial arthrosis. Eight of these had required further surgery and of the remaining 81 knees 45 were good and 36 were not. Lasting pain relief was clearly associated with correction of the mechanical axis of the knee; this was more difficult to achieve in severe stages of the disease. In 22 of 24 corrected knees further progress of the disease had not occurred, and six of these had radiographic signs of cartilage repair. By

contrast two thirds of the under-corrected knees had further progress of the disease. The opposite compartment did not suffer from the increased load on the articular cartilage; only three over-corrected knees showed cartilage narrowing and were pain-less.

It is concluded that high tibial osteotomy is a reliable method for definitive treatment of early medial type gonarthrosis provided the radiographically defined mechanical axis is adequately corrected.

ACKNOWLEDGEMENT

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TECHNICAL ACCURACY IN HIGH TIBIAL OSTEOTOMY FOR
GONARTHROSIS

by

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TECHNICAL ACCURACY IN HIGH TIBIAL OSTEOTOMY FOR GONARTHROSIS

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A preoperative roentgenological analysis of the whole leg in the standing position is presented as an aid in high tibial osteotomy for medial oosteoarthritis of the knee. This analysis provides information about the mechanical condition of the knee, the extent of the deformity and the exact size of the wedge of bone to be excised during the operation. The initial experience with this method is encouraging. In 66 osteotomies four-fifths had a postoperative correction within $\pm 3^\circ$ of the predicted angle and after 1 year two-thirds were still within this range.

Key words: gonarthrosis; osteoarthritis; tibial osteotomy

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High tibial osteotomy is universally accepted as the treatment of choice for early stages of medial gonarthrosis. The effect of the operation is correlated with the correction obtained (Bauer et al. 1969, Coventry 1965, 1973, Hagstedt 1974, Seal & Chan 1975).

The closing wedge osteotomy above the tibial tubercle is a safe operation (Jackson & Waugh 1974) but it needs improvement as regards accuracy. In an earlier series from this hospital (Hagstedt 1974) in 59 out of 166 knees the planned correction was not achieved.

This paper describes our efforts to increase the precision in high tibial osteotomy by improving the preoperative roentgenological examination and modifying the operation method.

MATERIAL

In the Orthopaedic Department of the University Hospital of Lund, 59 high tibial osteotomies were

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performed during the years 1975-1977. Seven osteotomies were performed at the Orthopaedic Department of the Hospital in Eksjö during the years 1976-1977. The same indications and pre- and postoperative routines were used for these 66 knees in 60 patients, 29 men and 31 women.

The indication for operation was medial gonarthrosis stages I-III (Table 1, Ahlbäck 1968, Hagstedt 1974, Norman 1974). The condition was primary in 58 knees and secondary to osteonecrosis in three knees and to trauma in three knees. One young woman (two knees) had *genu varum* without pain. The ages of the patients ranged from 22 to 81 years with a mean of 56 years (Table 1).

METHODS

ROENTGENOLOGICAL METHOD

Theoretical background. On a long roentgenogram (Figure 1), the line between the centre of the femoral head and the centre of the talus represents the mechanical axis of the lower extremity. Normally this axis goes through the middle of the knee at the tibial spine. Any deviation from the

Table 1. Major radiographic stages of the medial type of gonarthrosis

Stage I	Joint space narrowing
Stage II	Joint space obliteration
Stage III	Minor bone attrition
Stage IV	Moderate bone attrition
Stage V	Major bone attrition

Subluxation (translation) of the tibia with secondary arthrosis of the lateral compartment is a common feature in Stage V medial gonarthrosis but may occasionally appear in earlier stages as a sign of ligamentous instability (Egund & Norman 1979).

mechanical axis represents the degree of varus or valgus malalignment of the knee (Fick 1916, Maquet et al. 1967, Mikulicz 1878).

Theoretical biostatic models of the knee have been developed by Maquet et al. (1966, 1967).

They, Ramadier (1967), and Harris & Kostuik (1970) have used this model in practical work during high tibial osteotomies. However, previous descriptions of the roentgenological technique have not been sufficiently accurate to permit an exact re-examination. In order to standardize the roentgenological examination, every angle should be measured in the plane of the angle, but there is at present no acceptable definition of these planes. Therefore Norman (1976) chose the lateral view of the knee for reference and defined the frontal plane as perpendicular to the lateral view.

Roentgenological technique. The patient is examined standing on one leg. The lateral view of the knee is monitored by fluoroscopy or by an ordinary roentgenogram. The frontal view is then taken perpendicular to this lateral view on a long cassette (100 cm) from a distance of 200 cm with the central ray passing through the knee (Figure 1a, b).

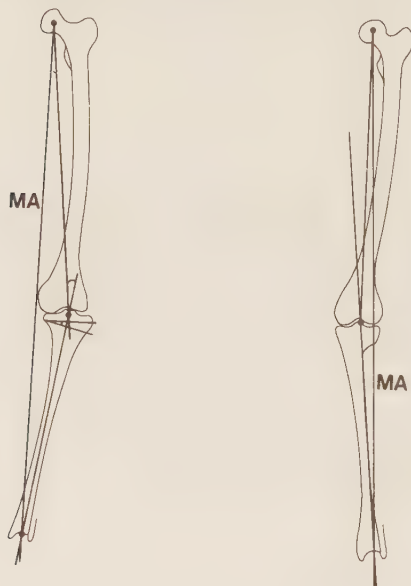
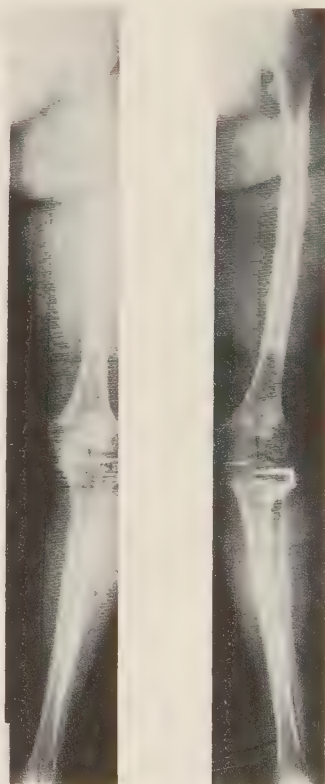


Figure 1a. Schematic drawing of the lower extremity showing the mechanical axis (MA), the angle of deformity and the change in the mechanical axis after tibial osteotomy. b. The roentgenological appearance of the situation described in a. A slight overcorrection is obtained after the osteotomy.



To correct the deformity with a high tibial closing wedge osteotomy the wedge to be excised should have the same angle in the same plane as the deviation angle (Figure 1a). Wedges with the desired angle are drawn on the roentgenogram at different levels parallel to the joint surface. The base of the wedge can then be measured on the lateral cortex, and the distance used by the surgeons in the operation (Figure 2). The long film focus distance eliminates the need to correct for geometrical magnification.

The vertical height of the wedge can be checked by geometrical calculation. The vertical height is equal to the wedge angle in radians multiplied by the true width of the tibia,

$$1^\circ = \frac{2\pi}{360} \text{ radians}$$

Postoperatively the correction was calculated from roentgenograms as the change in the angle

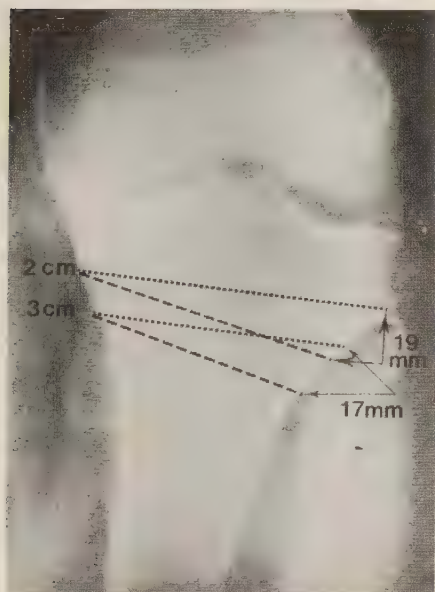


Figure 2. Medial gonarthrosis with a varus malposition of 12° . To correct the deformity with tibial osteotomy a wedge with the same angle should be excised. Two cm below the joint surface the distance on the lateral cortex is 19 mm and at 3 cm below 17 mm. Note that the proximal cut is parallel to the joint line.

between the plane of the tibial condyle and the longitudinal axis of the proximal half of the tibial shaft.

OPERATION

A closing wedge osteotomy was performed above the tibial tubercle according to Coventry (1965). The fibular head was partially resected parallel to the lateral tibial cortex, saving the lateral attachment of the collateral ligament. The dorsal aspect of the tibia was exposed with subperiosteal dissection to the medial margin of the tibia. The level of the osteotomy was decided and the height of the wedge on the lateral cortex was obtained from the roentgenological calculation. The osteotomy was made with an oscillating saw from behind and forwards. The osteotomy gap was closed with an intact periosteal lambeau medially and fixed laterally with a Coventry staple.

It should be noted that 1–2 mm of bone are lost as saw-dust and that it is important to place the wedge angle exactly at the medial cortex. When the osteotomy is done more distally, still above the tibial tubercle, every millimetre of bone lost laterally corresponds to a greater angle compared with that obtained with a more proximal osteotomy (Figure 2). Roentgenographic fluoroscopy was used during the operation to monitor these variables.

Postoperatively the patients were in plaster for 6 weeks and immediate weight-bearing was allowed. Roentgenological examination was made 1 day after the operation, at 1 week, at 6 weeks after the plaster was removed, and then at 1 year.

RESULTS

Our aim at the operation of the first 55 cases was to correct the angular deformity in the knee so as to make the weight-bearing line identical with the ideal mechanical axis, i.e. the line through the centre of the femoral head, the tibial spine and the midpoint of the talo-crural joint. For the last 11 osteotomies we have tried to achieve a valgus overcorrection of 4° .

Immediately after the operation four-fifths of the knees were corrected to within $\pm 3^\circ$ (Figure 3). At the 1 year follow-up the correction had been lost in several cases; however two-thirds of the knees remained within $\pm 3^\circ$ of the planned correction. Thirty-two knees

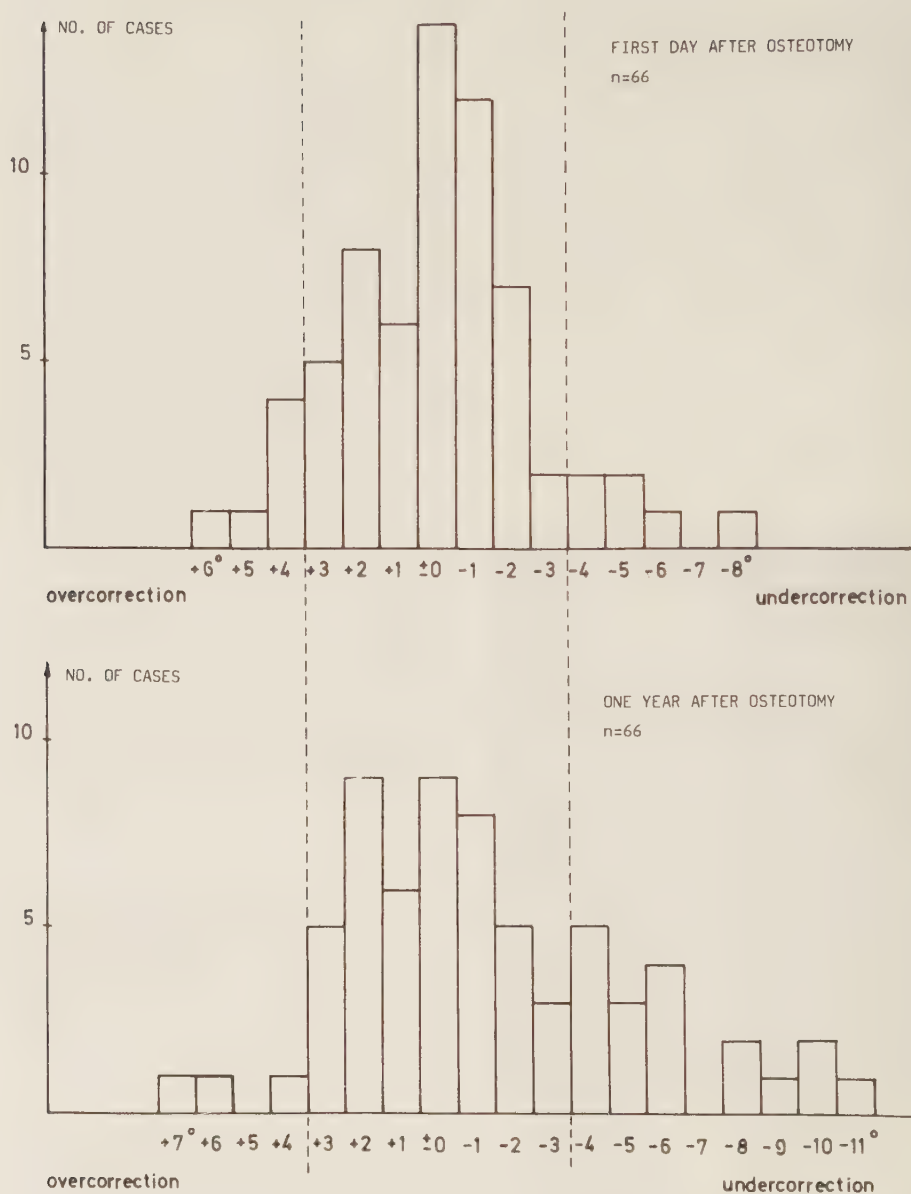


Figure 3. Deviation from the predicted correction. (above) First day after operation. (below) Situation 1 year after operation.

showed a decrease in their correction, 17 knees an increase and 17 knees maintained their initial correction (Figure 4). The loss of correction was less than or equal to 4° in 21 out of 32 knees. Only one knee had an increased correction of more than 4° .

DISCUSSION

In high tibial osteotomy a variety of principles have been applied in order to calculate the deformity that should be corrected. Some authors have suggested that the

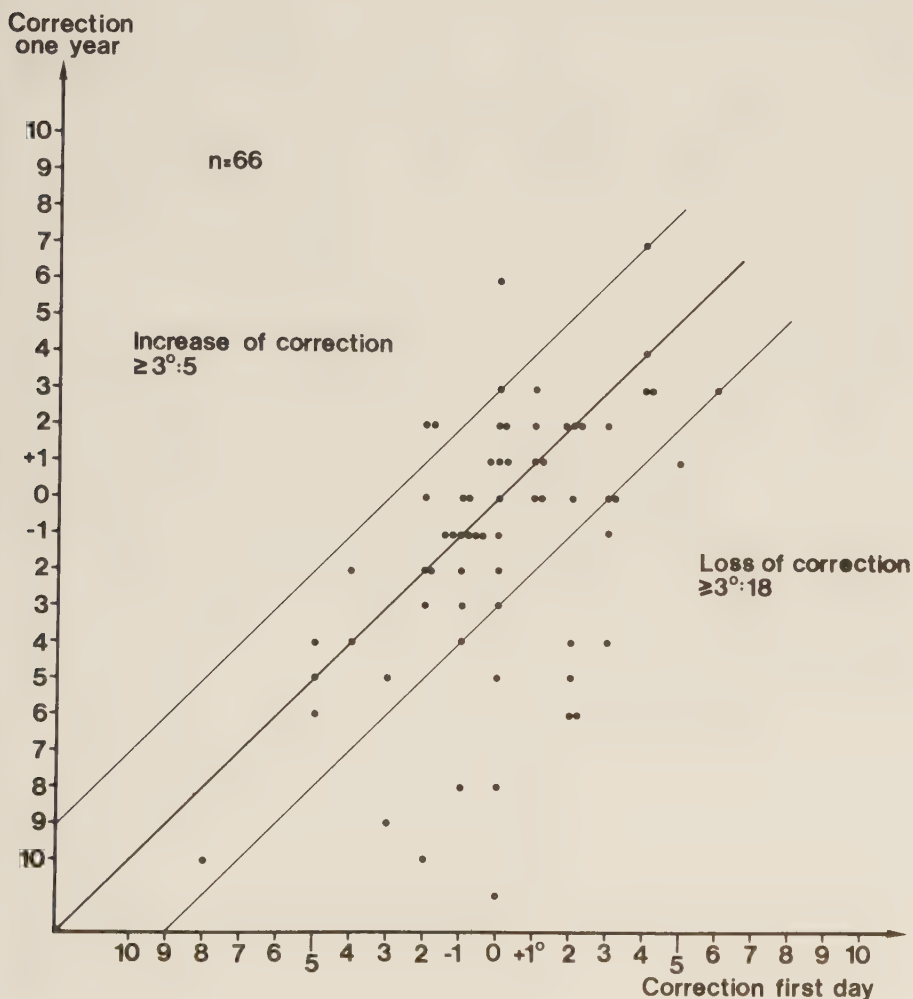


Figure 4. Increase or loss of correction in 66 osteotomies. The Zero line and the lines for $\pm 3^\circ$ are drawn.

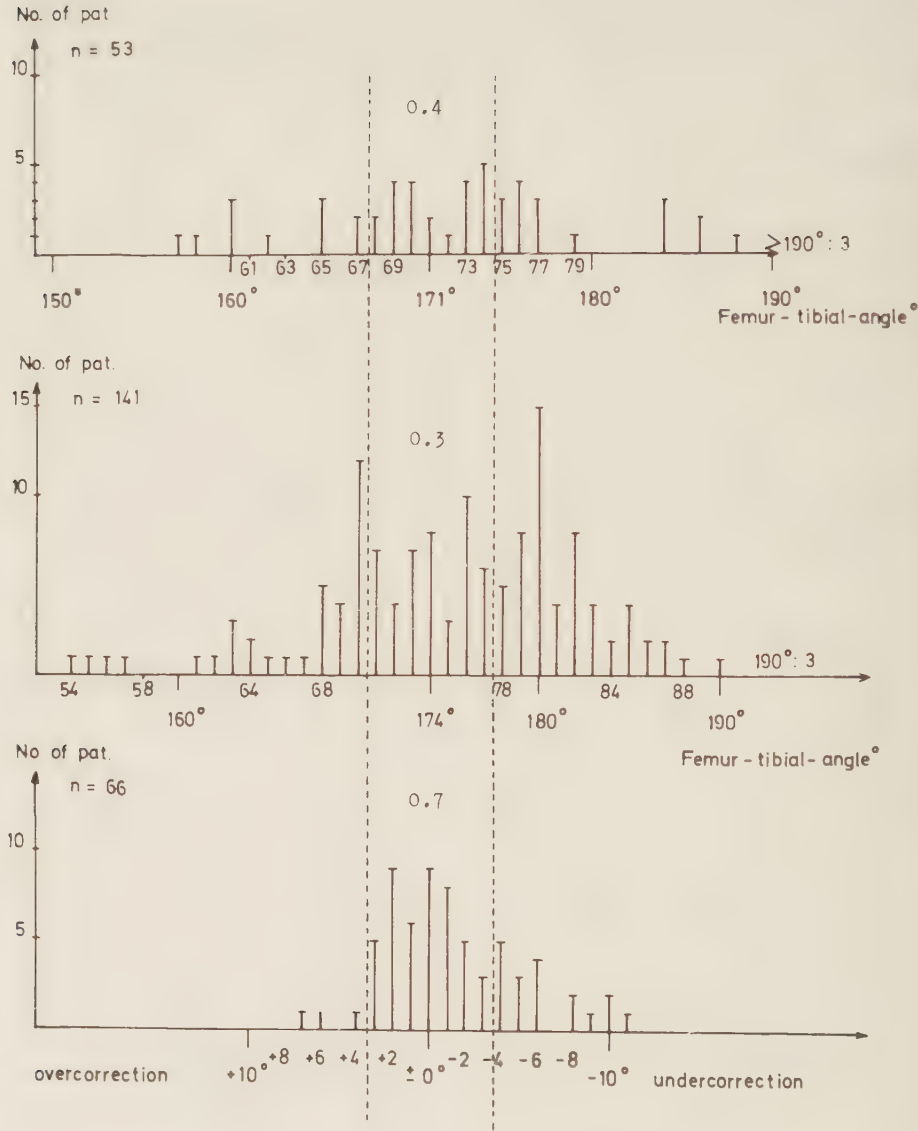


Figure 5. Comparison of the correction in the follow-up materials from (top) Bauer et al. (1969), (middle) Hagstedt (1974), and (bottom) present material.

angle between the axes of the shafts of the femur and the tibia should be within the interval 164° – 178° with 174° as the ideal angle. Both weight-bearing and non-weight-bearing pictures have been used (Bauer et al. 1969, Coventry 1973, Hagstedt 1974, Kettelkamp et al. 1976, Shoji & Insall 1973, Slocum et al. 1974). Others have tried to determine the mechanical axes of the knee (Harris & Kostuik 1970, Maquet et al. 1966, 1967, Ramadier 1967) and at the operation corrected the deformity in such a way that the mechanical axis should then pass through the centre of the knee.

In an earlier series of 166 osteotomies we aimed at a femoro-tibial angle of 174° at weight-bearing (Hagstedt 1974); the wedge height was calculated using 1° equal to 1 mm (Bouillet & van Gaver 1961), which is true when the width of the tibia is about 6 cm. The method was abandoned because of the low level of accuracy of the correction at the follow-up. Instead the calculation was made on the roentgenogram of the whole leg where the weight-bearing conditions were visualized. The film was taken with the patient standing on one leg with the frontal plane exactly defined. In this way we avoid the errors in measurement caused by too small films, by curvation of the femur and tibia in the frontal plane, and by partial weight-bearing.

The procedure is as close as we can get to the theoretical biostatic model of the knee under weight-bearing conditions. Earlier reports of similar methods have not described any standard methods for the measurements and the frontal plane has not been defined.

Edholm et al. (1977) have reported a roentgenological method with the orthoradiographic technique adding also another parameter, joint laxity. The non-weight-bearing leg is examined under standardized conditions but the assumption that the mechanical axis should coincide with the arithmetic medium of the laxity in an osteoarthritic knee has not been proven.

The method described here gives precise

preoperative information to the surgeon. The postoperative results show that it is also useful in practice (Figure 5). At 1 year following surgery in our series two-thirds of the cases were within $\pm 3^{\circ}$ of the planned correction as compared to about one-third of the cases of Bauer et al. (1969) and Hagstedt (1974). Bauer et al. used an interval of around 171° and out of 53 cases of medial arthrosis 23 were found to be within $\pm 3^{\circ}$. Hagstedt described 141 cases of medial arthrosis and in 45 cases the correction was within $\pm 3^{\circ}$.

The surgically obtained correction had the same level of accuracy as that obtained when operating with a saw jig (Myrner 1978).

In our series the postoperatively obtained correction had changed by the time it was measured at the follow-up after 1 year. Initially 54 out of 66 knees were found to be within $\pm 3^{\circ}$ of the planned correction; 1 year later when the osteotomy was healed there were 45 cases with $\pm 3^{\circ}$. Half of the osteotomies lost correction and in one-fourth the loss exceeded 3° (Figure 3).

Postoperative loss of correction has been observed previously (Hagstedt 1974, Seal & Chan 1975) but it has not been quantified. It appears that loss of correction is a factor which cannot be completely controlled. This together with biomechanical arguments suggests that an overcorrection should be performed in knees with medial gonarthrosis. Therefore in a continued prospective study we now aim at an overcorrection of 4° .

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TIBIAL OSTEOTOMY IN MEDIAL GONARTHROSIS

The importance of over-correction of varus deformity

by

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SUMMARY

In a prospective series of 52 knees selected for high tibial osteotomy because of early medial arthrosis, special care was taken to obtain a final over-correction in valgus. The operative procedure and the pre- and postoperative radiographic examinations were standardized and the follow-up was 1-3 years. Forty-nine of the 52 knees had obtained a normal or over-corrected mechanical axis. Forty-five of these had improved pain-free walking distance, and 31 were pain-free. In 45 knees the arthrotic condition had not progressed, and in five of these there were signs of cartilage restitution.

It is concluded that precise correction of medial gonarthrosis can be achieved, and this provides a rational basis for definitive treatment of early stages of this condition; for the majority an endoprosthesis operation should not be needed in the future.

INTRODUCTION

The beneficial long-term effect of tibial osteotomy in gonarthrosis is due to the re-distribution of body-weight from the arthrotic femoro-tibial compartment to the opposite healthy one (Maquet et al. 1967, Bauer et al. 1969, Kettelkamp et al. 1976, Coventry 1979). In lateral arthrosis tibial osteotomy for correction of valgus deformity rarely produces a stable knee and this operation is now being discarded in favour of the femoral osteotomy or arthroplasty (Shoji and Insall 1973, Hagstedt 1974, Coventry 1979, Tjörnstrand et al. in press). In medial gonarthrosis the immediate postoperative correction of varus deformity by tibial osteotomy is often lost during the healing period so that the aim of the operation is only partly achieved (Hagstedt 1974, Seal and Chan 1975, Insall et al. 1974, Coventry 1979, Koshino and Tsuchiya 1979, Tjörnstrand et al. in press).

We therefore started a prospective study of tibial osteotomy for correction of varus deformity in gonarthrosis with a rather rigid selection of patients and

precise definition of the operative aim. Only cases with early medial arthrosis were selected for the osteotomy, and the patients were usually below 70 years of age. The radiographic methods and operative technique were standardized in order to obtain an over-correction in valgus with the mechanical axis lateral to the intercondylar eminence as the final result.

MATERIAL

In the Department of Orthopaedic Surgery in Lund and Eksjö 52 knees with medial arthrosis having caused at most minor bone attrition were subjected to high tibial osteotomy during the period 1976-1978 (Table 1); the follow-up was at least 12 months. There were 22 female and 30 male knees in 50 patients. The majority of the patients were below 65, the mean age was 56 years, and the age range 36-76. The stage of arthrosis was determined pre-operatively from radiographs obtained in stressed, weight-bearing position (Hagstedt 1974). The majority of the knees had no bone attrition (Table 1). The preoperative varus deformity was recorded from a whole limb radiograph on the affected side (Egund 1979, Hagstedt et al. 1980) and varied between 4° and 18° with a mean value of 9° .

Table 1. Major radiographic stages of medial type of gonarthrosis (Ahlbäck 1968).

	No. of knees
Stage I Joint space narrowing	17
Stage II Joint space obliteration	22
Stage III Minor bone attrition (< 0.5 cm)	12
Stage IV Moderate bone attrition	0
Stage V Major bone attrition (> 1 cm)	1

Subluxation (translation) of the tibia with secondary arthrosis of the lateral compartment is a common feature in Stage V medial gonarthrosis but may occasionally appear in earlier stages as an effect of ligamentous instability.

METHODS

Clinical examination

A distinction was made between pain on weight-bearing and pain at rest. Weight-bearing pain was recorded as the pain-free walking distance, and pain at rest was recorded as continuous or after exercise. The patients' own opinions as regards change in walking ability were recorded.

A mobile knee was defined as a knee with a range of motion more than 90° and an extension defect not more than 5° . A stable knee had no lateral thrust on walking (Bauer et al. 1969, Hagstedt 1974).

Radiographic examination

Stressed knee radiograph (standing): Preoperatively the patients were examined in standing position with the knees stressed in varus and valgus to visualize the height of the articular cartilage. The same examination was done at the follow-up.

Tibial radiograph (laying): The immediate postoperative correction was measured on frontal radiographs of the tibia as the change of the angle between the tibial anatomic axis and the tibial articular plane. Repeated such observations were done during the first postoperative year.

A whole lower limb radiograph (standing): For determination of the mechanical axis which was done before the operation and at the follow-up, a whole lower limb radiograph was used (Egund 1979, Hagstedt et al. 1980). The deviation of the mechanical axis from the ideal position transecting the centre of the knee was measured as the angle between the lines from the centre of the intercondylar eminence to the centres of the femoral head and the talo-crural joint, respectively.

Pre- and postoperative radiographs of the patellar articulation were obtained in axial projections with the knee in 30° and 60° flexion.

Correction: Correction or over-correction was recorded when the mechanical axis transected the centre of the knee or fell laterally.

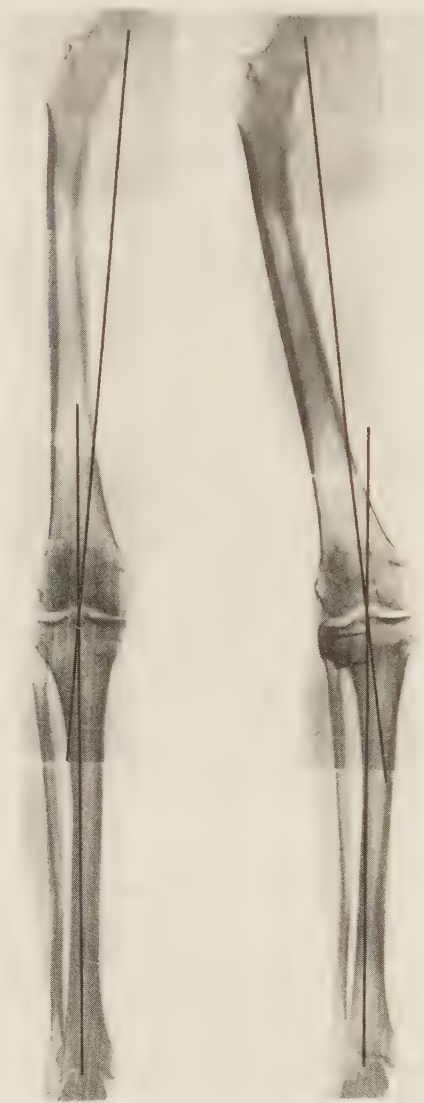


Fig. 1. Whole lower limb radiograph in standing position in a man 52 years old with medial arthrosis Stage I in his right knee (left). The varus deviation of the mechanical axis is 5° . One year after the osteotomy the deviation of the mechanical axis is 8° valgus and the medial joint space has now opened up in the standing position (right).

The operation

In this series the aim at the operation was to achieve an over-correction of the mechanical axis to 4° of valgus in order to compensate for the postoperative loss of correction known to occur. The wedge calculation was done graphically on the preoperative whole lower limb radiograph (Fig. 1) (Hagstedt et al. 1980).

The operation was performed as a closing wedge osteotomy preserving the medial periosteal and fascial structures and using a Coventry (1973) staple as internal fixation laterally. Postoperatively the patient had a plaster from groin to ankle in most cases for six weeks; during this period full weight-bearing was encouraged.

Satisfactory knee function. To assess the knee function we used a Venn diagram according to Bauer et al. (1969) with the modification of the pain parameter according to Jónsson (1981) and Tjörnstrand et al. (in press). Satisfactory knee function was present in a knee which was mobile, stable and pain-free, i.e. had a pain-free walking distance exceeding 500 metres.

Statistical analysis

Chi-square tests with Yates' correction was used.

RESULTS

Complications. In the 52 cases we had ten operative complications of which three needed further surgery.

One knee had a postoperative wound infection with septic arthritis which was treated with antibiotics, drainage of the joint and extraction of the staple. At follow-up the preoperative range of motion had not decreased, the weight-bearing pain medially had disappeared, but the patellar articulation now caused pain. - One wound infection needed staple extraction

before healing. - Two superficial infections healed on antibiotics. - One wound necrosis healed on conservative treatment. - Two peroneal palsies recovered completely, one spontaneously, and one after the nerve had been explored and released. - Two cases of deep venous thrombosis required anti-coagulant therapy. At the follow-up there were no signs of postthrombotic problems. In one knee there was a fracture without displacement through the proximal fragment. This was not observed initially, the patient followed the standard postoperative regime, and the knee ended up with satisfactory function.

Operative accuracy registered on tibial radiographs

Immediately after the operation 44 of the 52 knees were within $\pm 3^\circ$ of the aimed correction. One year later 35 knees were within this interval.

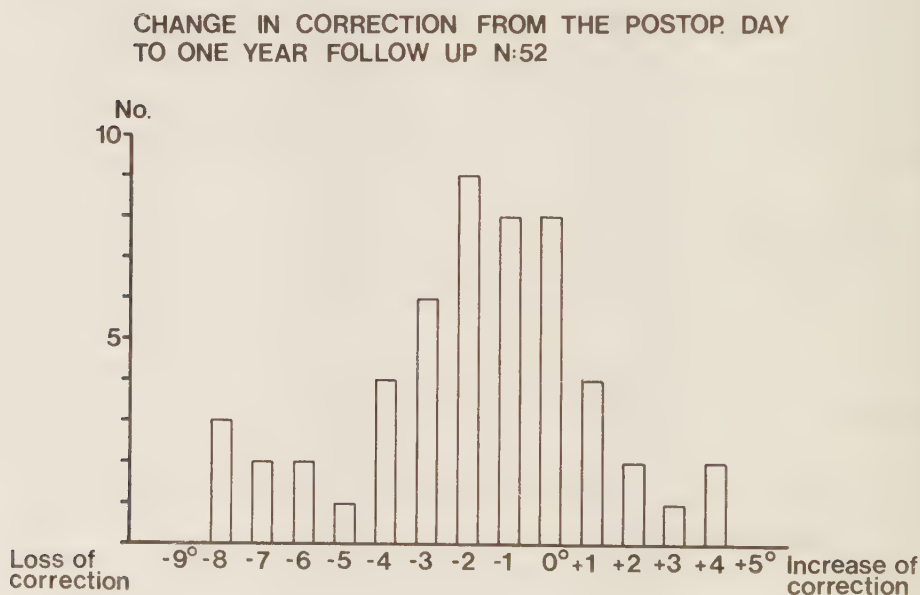


Fig. 2. Loss of correction during the first year. The correction was measured on ordinary frontal tibial radiographs as the change in the angle between the articular plane and the anatomic axis of the tibia. The angle was measured at the immediate postoperative control and at the one year follow-up.

Within $\pm 4^{\circ}$ were 47 knees postoperative and also at the follow-up. Thirty-five knees had a loss of correction, at most 8° ; nine knees had an increase of correction, at most 4° ; eight knees had kept their initial correction. A change of correction less than or equal to 4° occurred in 44 knees (Fig. 2).

Operative accuracy registered on whole lower limb radiographs

At the one year follow-up 37 knees had a deviation of the mechanical axis less than or equal to 4° from the 4° valgus aimed at. Three knees were clearly under-corrected to 7, 8 and 13° of varus. One knee had but 1° of varus and was accepted in the corrected group (Fig. 3).

**DEVIATION OF MECHANICAL AXIS ONE YEAR
AFTER TIBIAL OSTEOTOMY N:52**

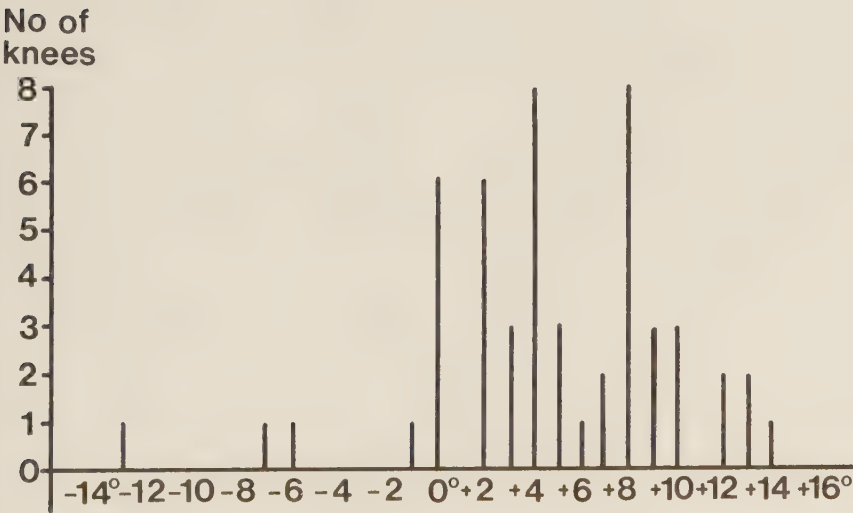


Fig. 3. The diagram shows how the mechanical axis falls through the knee one year after the osteotomy. The angle is measured between the lines from the centres of the femoral head and the ankle joint to the intercondylar eminence, respectively.

Table 2. Discrepancy between the correction of the mechanical axis and the osseous correction in 49 corrected/over-corrected knees after tibial osteotomy for medial gonarthrosis.

Discrepancy	-5°	-4°	-3°	-2°	-1°	0°	+1°	+2°	+3°	+4°	+5°	+6°	+7°	+8°	+9°	+10°	+11°
No. of knees			1	2	5	8	6	4	4	4	4	4	4	4	2	2	1

This table shows the subtraction of the osseous correction (the change in angle between the tibial anatomic axis and articular plane) from the angular correction of the mechanical axis of the knee.

A comparison of the osseous correction measured on the tibial radiographs and the correction of the mechanical axis measured on whole lower limb radiographs is shown in Table 2. Those knees which had the greatest instability (change in femoro-tibial angle in stressed knee radiographs) also had the greatest discrepancy between the osseous and the mechanical axis correction. The instability which contributed to the varus deformity before the operation now increased the valgus position after the operation.

Clinical results

Of the three under-corrected knees two were satisfactory and one was not. These three under-corrected knees are excluded in the following analysis of the corrected/over-corrected knees in the prospective series.

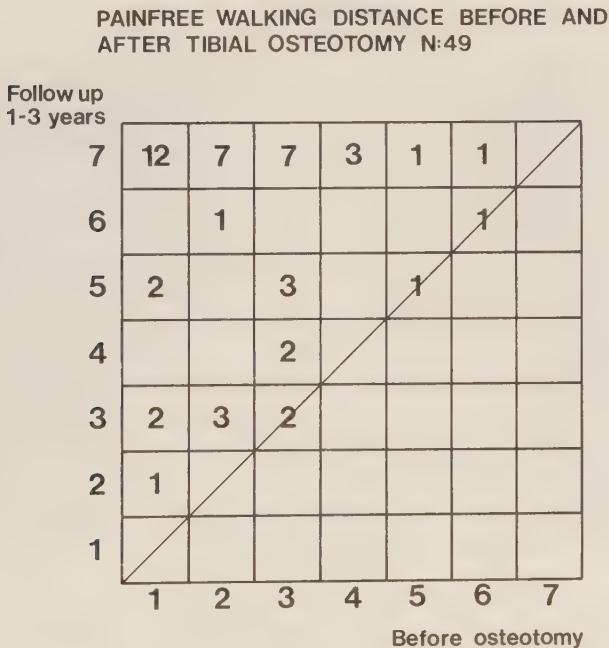


Fig. 4. The pre- and postoperative pain-free walking distance was classified in the following categories; (1) pain from the first step, (2) pain before 100 metres walking, (3) pain after 100 metres but before 500 metres walking, (4) pain after 500 metres but before 1 000 metres walking, (5) pain after 1 000 metres walking, (6) only starting pain, (7) no pain on walking.

Pain. All 49 corrected/over-corrected knees had weight-bearing pain before the operation; at the follow-up 45 had improved pain-free walking distance ($p < 0.001$) and four were unchanged (Fig. 4). No pain on walking was recorded in 31 knees ($p < 0.05$), 12 of which had pain from the first step preoperatively.

Before the osteotomy 13 knees had continuous pain, 22 had pain after exercise, and 14 had no pain at rest. After the osteotomy two knees had continuous pain, ten had pain after exercise, and 37 had no pain at rest ($p < 0.05$).

Walking ability. The patients' own opinions on improvement in walking showed that 37 knees were improved in this respect ($p < 0.01$) and 11 were unchanged. One patient had impaired walking ability because of worsened general condition, but the knee was pain-free.

Mobility. All but two knees had a range of motion more than 90° before the operation. These two knees had posttraumatic arthrosis with range of motion 30 and 60° , respectively. After the osteotomy 47 knees had more than 90° of motion; one knee had a decrease from 115 to 80° ; one knee had improved from 60 to 120° . Thirty-two knees now had more than 120° range of motion versus 21 knees before the osteotomy.

Stability. Fourteen knees had a lateral or dorsal thrust on walking before the osteotomy. At the follow-up there were no unstable knee by this definition.

Stage of arthrosis. At the follow-up there was further progress of arthrosis in four of the 49 corrected/over-corrected knees and in two of the three under-corrected knees. In 45 knees the condition had not progressed and five of these could not be stressed into the preoperative position (Fig. 5); the joint line was now clearly visible at the medial compartment.

Lateral compartment. In only one of the knees there were signs of affection of the articular cartilage in the lateral compartment at the time of follow-up.

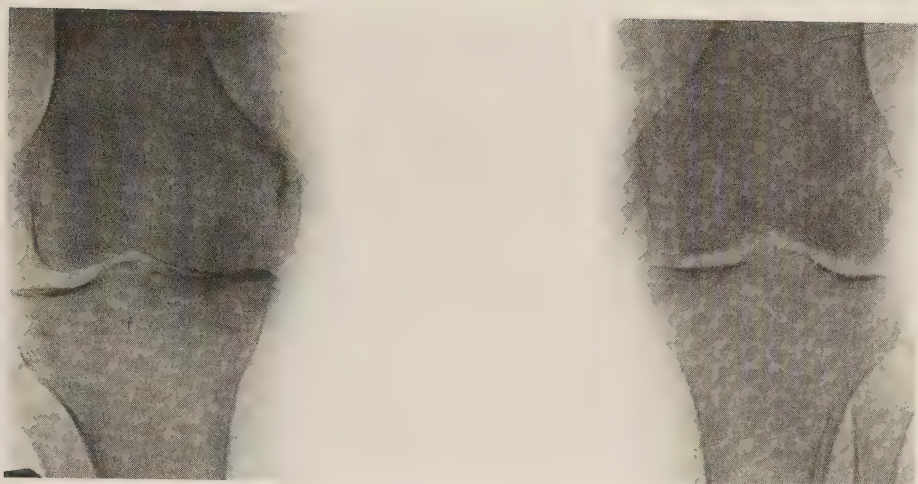


Fig. 5a.

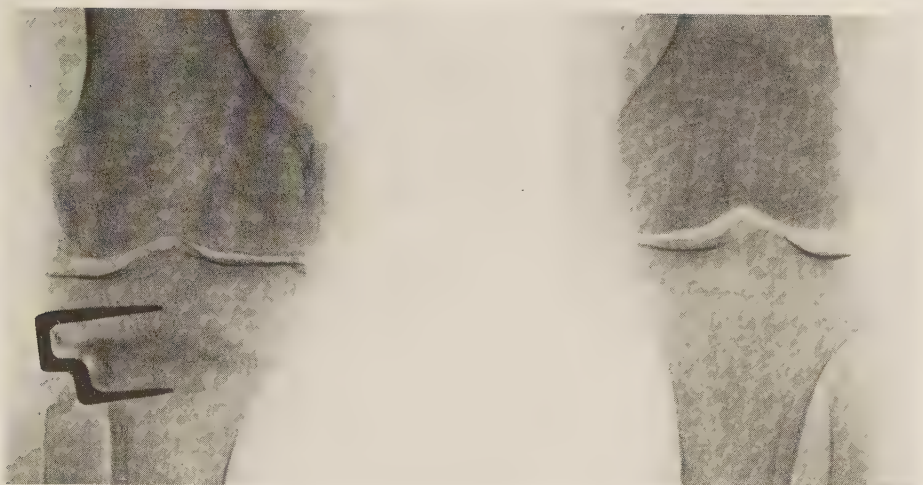


Fig. 5b.

Fig. 5. Varus stressed knees of a 50 year old woman. She had Stage II medial arthrosis on the right side before the operation (Fig. 5a). At the one year follow-up it was not possible to stress her knees to the same stage of arthrosis (Fig. 5b); now the appearance is of Stage I medial arthrosis, i.e. merely narrowing rather than obliteration of the joint space.

DISCUSSION

Clinical evaluation

Level of function in early medial gonarthrosis. There is widespread agreement that tibial osteotomy is the preferred treatment for early, medial type gonarthrosis (Bauer et al. 1969, Insall and Shoji 1974, Seal and Chan 1975, Hagstedt 1974, Jackson and Waugh 1974, Coventry 1979, Tjörnstrand et al. in press). In this prospective series most of the patients were less than 65 years old and only one had more than 1/2 cm of bone attrition. In this early phase of the disease the patient is not critically disabled. Many of our patients had a normal range of motion and all but two more than 90°. The pain on walking appeared in several cases only after 100 metres (Fig. 4), and the majority of the patients could walk more than 1 000 metres. By the London Hospital rating system (Freeman et al. 1977) six patients had acceptable knee function preoperatively. Maintenance of this functional level is a good result in the long run; untreated gonarthrosis is a progressive disease with poor prognosis (Hernborg 1978), and tibial osteotomy with adequate correction usually gives permanent good results (Tjörnstrand et al. in press, Seal and Chan 1975, Coventry 1979).

Satisfactory results. Like Hagstedt (1974) and Myrnerets (1979) we have measured the gain of the osteotomy in improvement of the pain-free walking distance, but we have forced the criteria for satisfactory knee function by accepting the definition of Jónsson (1981) to include, in addition to stability and mobility, a pain-free walking distance more than 500 metres. However, knees which did not fulfil the latter criteria could still have improved walking ability. We therefore introduced the relative concept pain relief for those knees which had improved pain-free walking distance to more than 100 metres.

For knees with good preoperative function, an improvement is hard to achieve. This is exemplified by one case who had no pain relief but a satisfactory knee function both pre- and postoperatively. In such cases an osteotomy is a

RESULTS AFTER TIBIAL OSTEOTOMY WITH OVERCORRECTION IN MEDIAL GONARTHROSIS

24 corrected/overcorr. knees
(Tjörnstrand et al -81)

49 corrected/overcorr. knees
(Present series)

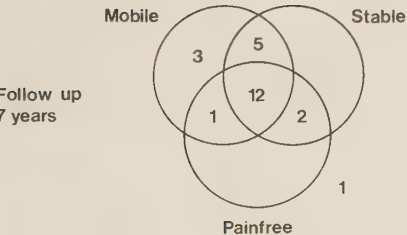
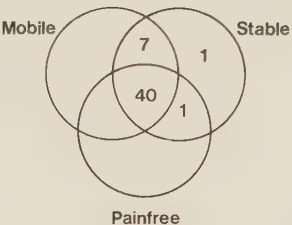
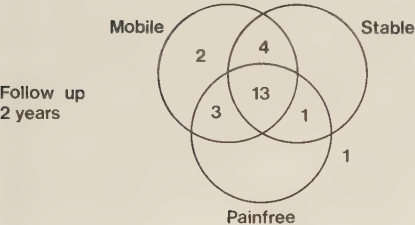
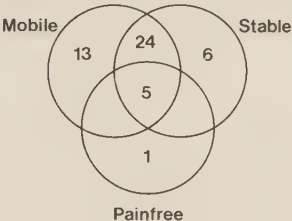
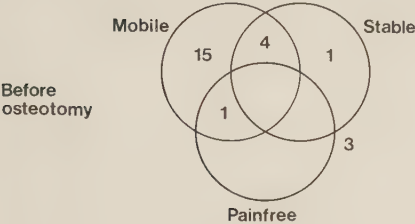


Fig. 6. Comparison of two series of knees operated with tibial osteotomy for medial gonarthrosis and in which the mechanical axis had become normal or over-corrected. The 24 knees from Tjörnstrand et al. (in press) were followed for more than seven years and had the same results at the two and the seven year follow-up. In the present series the clinical results at the follow-up were better with 41 pain-free knees of 49.

preventive operation motivated by ours and others findings of good results in this progressive disease.

Despite this rigorous definition 40 of the 49 corrected/over-corrected knees in this series acquired satisfactory function and 41 permitted walking more than 500 metres without pain. This is an improvement compared with earlier results from our departments (Hagstedt 1974, Tjörnstrand et al. in press) (Fig. 6).

Patellar arthrosis. In eight cases with not satisfactory knee function we found co-existant patellar arthrosis in six. However, earlier authors have not found patellar arthrosis a contraindication to osteotomy; Goutaillier et al. (1979) reported improvement of patellar symptoms after osteotomy; they recommended tibial osteotomy in cases with medial and co-existant patellar arthrosis with surgery for the patellar arthrosis as a secondary procedure if required. Others have combined the osteotomy with ventralisation of the distal fragment (Maquet 1976). Since at least half of the cases with co-existant patellar arthrosis become satisfactory and the result of the ventralisation operation is unpredictable (Lund 1978), we have not changed our previous attitude which is in accordance with Goutaillier et al. (1979).

Pyrophosphate arthritis. One knee in the present series had both arthrosis and pyrophosphate arthritis. This knee was classified as a failure (not pain-free). Coventry (1979) regards pyrophosphate arthritis as a relative contraindication to osteotomy. In our previous series (Tjörnstrand et al. in press) there were three corrected cases with medial arthrosis and pyrophosphate arthritis; one of them was a failure according to the definition above. In Jónsson's (1981) series of Marmor arthroplasties 21 cases had pyrophosphate arthritis; 13 of them were not satisfactory and five were failures. These observations indicate that surgery for only compartment of the arthrotic knee, osteotomy or arthroplasty, is unsuitable in cases associated with pyrophosphate arthritis.

Plaster immobilisation - knee mobility and early weight-bearing

Myrnerets (1979) uses passive movements the first two weeks after the operation and then immobilisation in a walking cast. Others (Maquet, Beltrami and Jackson) have used external fixation with compression devices which incur the risk of pin tract infection. However, in this material plaster fixation was not observed to cause impaired knee mobility; a few knees had decreased range of motion after the operation, more had improved in this respect, and the majority had unchanged acceptable knee motion.

Coventry (1979) and Myrnerets (1979) do not allow full weight-bearing until radiographic healing has occurred. They point out delayed or non-union and loss of correction as the disadvantage of early weight-bearing. Before we modified our surgical technique (Hagstedt et al. 1980) we had several non-unions (Tjörnstrand et al. 1978), but in our latest 105 osteotomies there were none. The change in correction measured on tibial radiographs are with few exceptions within $\pm 4^\circ$ (Hagstedt et al. 1980), and with the nearly exact method of roentgen stereophotogrammetry (Selvik 1974). We have confirmed these findings in a current series (Tjörnstrand et al. to be published).

In our experience early weight-bearing in plaster has not impaired healing of the osteotomy in the desired position, for the patient the rehabilitation period has been considerably less difficult, and the range of motion has not deteriorated.

Results in different stages of arthrosis. In the series of Tjörnstrand et al. (in press) there were nine knees not pain-free in 24 over-corrected knees with medial arthrosis. Twelve out of the 24 knees had arthrosis Stage III or more, and seven of the nine failures were in this category. Also in this series there was a slight overrepresentation of Stage III arthrosis among the failures. These findings do not agree with Myrnerets (1979) who used the same staging but found several good results in Stages III, IV and V. An explanation for this could be differences in the knee rating (he used the patients' opinion). We have interpreted our findings to indicate difficulties to achieve good results in advanced stages of arthrosis and that this further limits osteotomy to

be the choice for treatment of early gonarthrosis. For Stage IV and V arthrosis endoprosthesis should be preferred, and the further development of the operative technique now ensures good results for the majority (Jónsson 1981).

RADIOGRAPHIC OBSERVATIONS

Degenerative changes. At the follow-up the varus-valgus stressed radiographs showed that the articular cartilage in the opposite lateral compartment had remained intact in all but one of the 49 corrected/over-corrected knees. Here the deviation of the mechanical axis was 7° of valgus and the knee suffered from pyrophosphate arthritis.

In a few cases only the medial compartment disease had progressed. Here we had a short observation time but in our earlier report on 89 osteotomies for medial arthrosis, followed-up for more than seven years, progress was common in the under-corrected group and uncommon in the corrected group (Tjörnstrand, in press). These findings seem to agree with Coventry (1979), Maquet (1976) and Kettelkamp et al. (1976), but strict comparison with these authors cannot be made because they did not record the stage of arthrosis in radiographic parameters. In five cases there might be cartilage repair; despite stressing the knee in varus at different degrees of flexion the joint space on the radiographs was higher than before the operation. Koshino and Tsuchiya (1979) and Coventry (1979) have reported similar findings supported by biopsy evidence of cartilage regeneration.

Correction. Several authors (Coventry 1979, Hagstedt et al. 1980, Myrnerets 1979, Ziller, Seyfarth 1974) have reported loss of correction during the first year after the tibial osteotomy. To compensate for this loss we have chosen to aim at 4° of over-correction. By using standardized and reproducible roentgen techniques to guide the operation we achieved that 47 of 52 knees had a correction $\pm 4^{\circ}$ from the aimed at the first postoperative control, i.e. an accuracy equal to Myrnerets (1979), who used the SAAB-jig, a specially designed instrument for the operation. One year later 47 of our 52

knees were in the same interval; of 44 knees with change of correction 35 had a loss of correction. The amount of change was less than or equal to 4° in 44 knees.

There is, however, another parameter which was not completely controlled, the joint laxity, primary or secondary to the cartilage or bone loss. This laxity explains the difference of correction measured pre- and postoperatively on the tibial radiographs versus the whole lower limb radiograph; the former shows the osseous correction and the latter the change in mechanical axis.

The greatest difference was observed in those knees which had the greatest laxity measured as the difference in femoro-tibial angle on the stressed radiograph in varus and valgus. These measurements are not without objections but they do provide a rough estimate of the laxity. We agree with Myrner (1979) that this laxity should be kept in mind to avoid too great over-correction. In the present series there were five knees with an over-correction more than 10° ; one was not satisfactory. In our previous series of 89 knees with 24 over-corrected knees (Tjörnstrand et al. in press) there were seven knees with over-correction more than 10° . Four of these were failures indicating the danger of excessive over-correction.

CONCLUSIONS

The results from this prospective consecutive series of high tibial osteotomy in medial gonarthrosis show that correction/over-correction can be achieved by combining careful preoperative radiographic analysis with standardized operative procedures. The clinical results from this procedure are best in early stages of the disease and in patients who are not too old.

These findings give us a rational base for treatment of early stage medial gonarthrosis. An endoprosthesis operation should not be needed in the future for the majority of these cases.

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ROENTGEN STEREOPHOTOGRAMMETRY IN HIGH TIBIAL
OSTEOTOMY FOR GONARTHROSIS

by

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SUMMARY

In three cases operated with high tibial osteotomy for medial gonarthrosis the exact method of roentgen stereophotogrammetry with tantalum balls as bone markers (Selvik 1974) was used to study angular and translational movements in three dimensions at the operation and during the healing period. Tibial osteotomy caused angular and translational movements even in planes where correction was not intended, and the stereo technique revealed that stability was not present when knee mobilisation started. Correlation between the stereo values and conventional radiographic measurements were best in the frontal plane (root mean square value of discrepancies 1.3°). Roentgen stereophotogrammetry gives superior information compared with the conventional radiographic technique, but it is concluded that the latter has sufficient accuracy for the clinical assessment of corrections in the frontal plane.

INTRODUCTION

Tibial osteotomy gives pain relief in most cases of medial gonarthrosis if adequate correction is obtained (Bauer et al. 1969, Hagstedt 1974, Harding 1976, Kettelkamp et al. 1976, Coventry 1979, Myrnerets 1979, Tjörnstrand et al. 1981a). A careful preoperative radiographic measurement has a crucial importance, and different methods have been used for these measurements (Maquet et al. 1967, Bauer et al. 1969, Harris 1970, Beltrami et al. 1975, Edholm et al. 1977, Hagstedt et al. 1980).

However, the accuracy of the radiographic procedures including the examinations and the measurements has not earlier been completely evaluated. This is the background for the present study where changes in angulation and translations in the frontal, sagittal and transverse planes were recorded by an exact technique in three patients operated upon with high tibial osteotomy. The roentgen stereophotogrammetric method with small tantalum balls as bone markers (Selvik 1974) was used. This technique has yielded a technical accuracy of about 0.01 mm in measurements of longitudinal

growth (Aronson et al. 1978) and 0.1° - 0.3° and 0.1 mm for rotation and translation in studies of spinal fusion (Olsson et al. 1976).

PATIENTS

In January 1980 high tibial osteotomies were performed in three patients with medial gonarthrosis.

Case A: A woman born in 1924. She had since two years weight-bearing pain in her right knee and the last six months pain from the first step. Radiographs showed a Stage II medial arthrosis (Fig. 1a).

Case B: A man born in 1916. He had since two years increasing weight-bearing pain medially in his right knee. Radiographs showed a Stage III medial arthrosis.

Case C: A man born in 1934. Medial meniscectomy was performed ten years ago in his left knee which had weight-bearing pain the last six years. Radiographs showed a Stage III medial arthrosis.

METHODS

Radiographic examinations

Stage of gonarthrosis. The degree of medial arthrosis according to Ahlbäck (1968) was determined on standing radiographs of both knees stressed in varus (Norman 1974).

Whole lower limb radiographs in a defined frontal projection. The examination was performed with the patient standing on the examined leg only, using two X-ray tubes, perpendicular to each other. The defined frontal plane was tangential to the most posterior aspects of the femoral condyles and was obtained by fluoroscopy in the lateral view. The lateral radiograph, however, included the knee and the proximal third of the leg only. This examination was performed preoperatively and at the final control.

The postoperative examinations were performed in the supine position using two X-ray tubes and projections comparable to those of the whole lower limb examination. The frontal tibial radiograph included the whole leg, but the lateral one the proximal third of the tibia only.

Radiographic measurements

The varus or valgus deformity of the knee was related to the lateral angle between the lines joining the center of the femoral head, the tibial eminence and the center of the ankle joint ($>180^\circ$ = varus, $<180^\circ$ = valgus).

In the frontal plane, the inclination of the tibial plateau was measured in relation to a line joining the center of the ankle joint and the center of the tibia one centimeter distal to the osteotomy; in the sagittal plane it was related to a short tibial axis distal to the osteotomy.

Translation between the osteotomy fragments was only recorded along the transverse axis at the medial cortex.

Operation technique

The operation was performed as a closing wedge osteotomy modified from Coventry (1965). The proximal tibia was exposed from the lateral side. The head of the fibula was partly resected. The medial periosteal and fascial structures were kept intact to stabilize the medial side. A Coventry staple was inserted laterally after the wedge was removed.

The leg was kept in a plaster cylinder for about six weeks; during this period the patient was allowed full weight-bearing after the first roentgen examinations.

Implantation of tantalum markers

Four weeks before the osteotomy tantalum balls with a diameter of 0.8 mm were inserted. The procedure was made in local anaesthesia with a special instrument (Aronson et al. 1974). This instrument, with a strong needle and

a piston driving in the ball, made it possible to place the balls in the cortical bone under the periosteum and in the cancellous bone of the metaphysis. Four of five balls were placed under the tibial joint surface with as much spread out as possible. The same number of balls was inserted distal to the intended osteotomy. In Cases A and C tantalum balls were also placed in the distal femur. The need for the calculations in terms of rigid-body displacements between bone segments was three balls in each part. To make calculations possible even if one ball was lost or loosened at the osteotomy 1-2 extra balls were inserted (Fig. 1b).



Fig. 1a. The right knee of Case A on a standing radiograph with the knee stressed in varus showing a Stage II medial arthrosis.

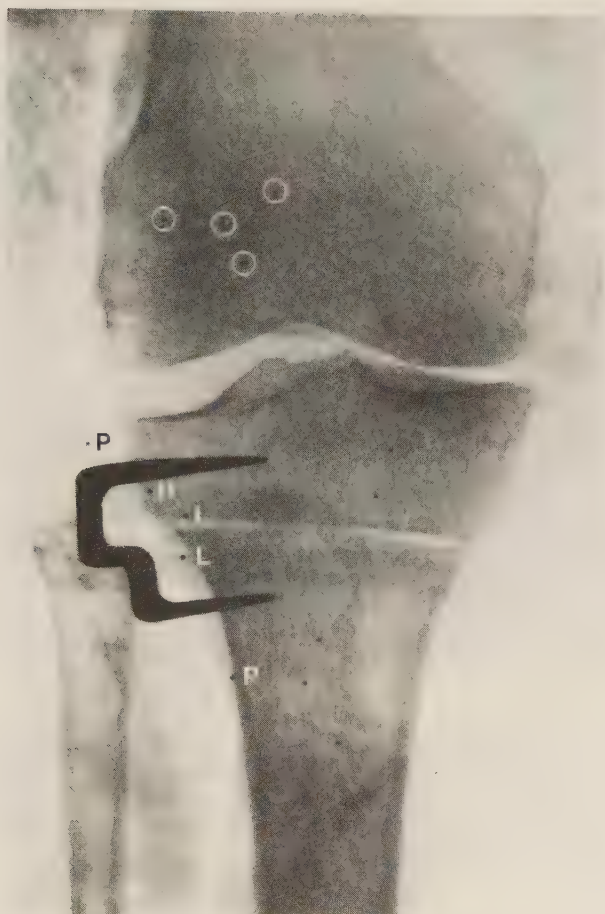


Fig. 1b. The first postoperative control of Case A. Small circles are drawn around the femoral implants. Excluded from the kinematic calculations were two implants (L) of which the proximal loosened between the 1 and 6 week control and the distal was by mistake implanted outside bone tissue. P = Periosteal balls. The periosteal ball in the proximal segment migrated 2.0 mm cranially during 18 weeks, but the one in the distal segment lay fairly stable. H = ball hidden in the lateral projection at some examinations. The balls in the distal segment should preferably have been more spread in space. This case illustrates well possible pitfalls in implantation of markers.

Roentgen stereophotogrammetry

Roentgen stereophotogrammetry according to Selvik (1974) was used. The bi-planar technique was employed. The knee was exposed in a calibration cage (Fig. 2) and frontal and lateral radiographs were obtained simultaneously.

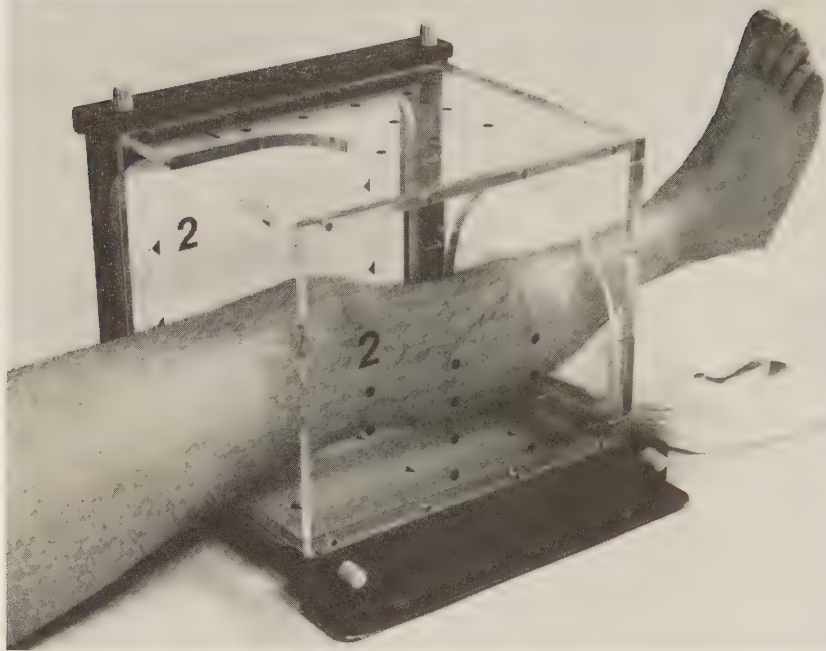


Fig. 2. The stereo calibration cage. The knee was examined with simultaneous exposures at right angles. Note the markings on the walls of the cage indicating the position of reference tantalum markings in the plexiglass. In relation to these the position of the implants could be exactly measured in a three-dimensional coordinate system.

The unloaded examinations were performed with the patient supine or standing with the examined leg hanging freely. Loading was achieved by letting the patient stand on the examined leg only.

The single problem in the photogrammetric reconstruction which gives the three-dimensional coordinates of the implants is to find the correct coupling between the frontal and lateral projections for implants which lie close to a transverse plane. This correspondence, however, is always correctly found using optimization principles in the computer programs. The accuracy in determining the three-dimensional position of the implants is about 0.05 mm (Selvik 1974).

Kinematic analysis

The implants proximal and distal to the osteotomy represent the two bone segments and constitute two rigid-body models. The rigid-body motion from the initial investigation to the succeeding ones, and the motion between two following investigations are calculated. The proximal segment is reoriented to its position at the initial examination, and the rotation angles and translations for the distal segment are calculated in the coordinate system of the first examination (Fig. 3).

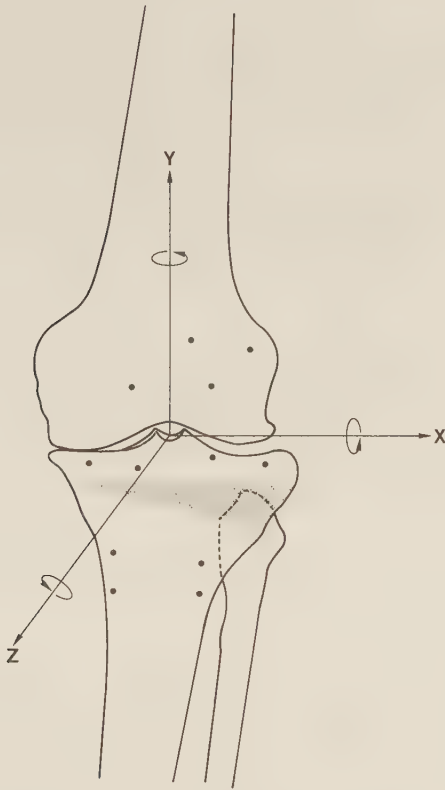


Fig. 3. Schematic drawing of the knee and the axes of the three-dimensional coordinate system defined by the calibration cage. The positive rotational directions about the axes are indicated.

Rotation angles calculated do not in principle depend on the position of the

implants. Translations are more complicated to present as they vary with the point in the body for which they are given, except when the motion is a pure translation (parallel displacement).

To get the most representative translation values three points were defined in the distal segment in the osteotomy plane using films from a postoperative examination. One point was taken at the anterior margin of the tibia, and one medially and one laterally on the posterior surface. The points formed an isosceles triangle with base 50 mm and height 29 mm, except for Case A where the base was 45 mm. These points were then transformed from the examination at which they were determined to the other examinations, including the preoperative ones, using the rigid-body model constituted by the implants in the distal segment. After that the translations of the points were calculated in relation to the proximal segment. The difference in translations computed by defining the points from another stereo examination was ascertained; for interpretative purposes the difference was found to be unimportant.

In Case A the corresponding procedure was performed for a point on each of the inferior joint surfaces of the femoral condyles, and the translations for these points in relation to the proximal tibial segment were calculated.

RESULTS

Angular movements

Angular corrections in the frontal plane aimed at and those measured by radiographic and by stereophotogrammetric technique, respectively, are presented in Table 1. The three-dimensional angular changes caused by the osteotomy are presented in Table 2. The three-dimensional changes from the first to the following unloaded postoperative investigations are presented together with the angular changes at the stability tests in Table 3.

Table 1. Comparison between the aimed and obtained correction in the frontal plane measured by tibial radiographs and by roentgen stereophotogrammetry.

Case	Aimed correction	Obtained correction			
		Tibial radiographs		Stereo roentgen	
		Postop.	Follow-up	Postop.	Follow-up
A	10°	10.5°	12°	10.3°	12°
B	17°	19.5°	14°	16.2°	13°
C	14°	16.5°	16.5°	18.5°	16.9°

Table 2. Angular changes caused by the osteotomy, measured by stereo roentgen on the first postoperative day. Positive values in the frontal plane reflect valgisation. Negative values in the sagittal plane reflect forward rotation of the distal segment. Negative values in the transverse plane reflect inward rotation of the distal segment.

Case	Frontal plane (Z-axis)	Sagittal plane (X-axis)	Transverse plane (Y-axis)
A	10.3°	-8.7°	-3.2°
B	16.2°	-5.7°	-0.8°
C	18.5°	-4.5°	-5.5°

Case A. Preoperatively a varus deformity was measured to 8°. An over-correction to 4° of valgus was intended (Tjörnstrand et al. 1981b). Laxity of the knee joint in the frontal plane was estimated to about 2°. The wedge angle was calculated to 10°; the laxity should provide for the correction to become 4° of valgus.

Frontal plane. On the tibial radiographs the correction at the time of operation was measured to 10.5°. At one week, 10 and 18 weeks this correction was 12.5°, 13° and 12°. Roentgen stereophotogrammetry showed in this plane a correction at the time of operation of 10.3°. During the first weeks the correction increased and then a decrease occurred to a final value of 12°. 18 weeks after the operation the valgus deviation was 3°, i.e. 1° from the intended angle.

Table 3. Roentgen stereophotogrammetry in high tibial osteotomy. Angular (degrees) correction changes and stability during the healing period. Changes in correction are represented as the difference between unloaded examinations and the first postoperative unloaded examination. Stability is represented by the rotations from the unloaded to the loaded examination on the same day. Positive values mean valgisation in the frontal plane, backward rotation in the sagittal plane and outward rotation in the transverse plane.

Case	Plane	Corr.change Stability	Time interval from the postoperative examination (weeks)					
A			1w	6w ^{x)}	10w	13w	18w	
	Frontal	Corr.change	3.1	3.8	1.8	y)	1.7	
		Stability	-1.6	-1.6	-1.0	0.6	-0.1	
	Sagittal	Corr.change	0.5	4.0	1.2	1.1	1.1	
		Stability	0.1	-3.2	-1.1	0.1	0.6	
	Transverse	Corr.change	-4.1	-3.9	-2.7	-2.9	-3.4	
Stability		0.3	1.3	-0.1	-0.6	-0.3		
B			1w	4w	5w ^{x)}	8w	12w	
	Frontal	Corr.change	-0.4	-1.0	-1.3	-2.9	-3.2	
		Stability	2.3	1.9	1.9	-0.2	0.2	
	Sagittal	Corr.change	0.1	0.2	-0.4	-0.9	-0.9	
		Stability	0.3	0.6	0.0	0.1	-0.6	
	Transverse	Corr.change	-1.8	-4.4	-4.6	-4.0	-3.3	
Stability		-1.5	-0.6	-0.5	0.0	-0.3		
C			2w	4w	6w ^{x)}	9w	13w	21w
	Frontal	Corr.change	-1.5	-0.4	-0.7	-0.5	-0.6	-1.6
		Stability	0.3	1.3	0.6	0.2	0.4	-0.1
	Sagittal	Corr.change	2.7	4.6	1.2	1.2	1.2	1.4
		Stability	5.1	0.8	-1.5	0.1	0.1	0.4
	Transverse	Corr.change	-1.1	-2.7	-2.4	-2.6	-3.0	-2.2
Stability		-0.7	-0.3	-0.3	0.7	0.1	0.1	

^{x)} Plaster removed.

^{y)} Uncertain unloaded value in the frontal plane due to a migrating implant and one hidden implant in this examination (Fig. 1b).

Sagittal plane. The radiographically recorded angular motion was at the time of operation 9° forwards of the distal segment. This decreased during the healing period with 4° to 5° at the 18-week control. Stereophotogrammetric calculations gave 8.7° angulation at the time of operation. During the healing period this value was rather stable and ended up with 7.6° forward rotation.

Transverse plane: Rotational movement around the longitudinal axis was only measured by roentgen stereophotogrammetry. The operation caused an inward rotation of 3.2° of the distal segment and this increased during the healing period and lay fairly stable between 3° - 4° more than at the immediate post-operative control.

Case B. The preoperative varus deformity was measured to 13° . An over-correction to 4° of valgus was intended.

Frontal plane. On tibial radiographs an operative correction of 19.5° was recorded. During the healing period the correction decreased. At 1, 5 and 12 weeks the correction was 17.5° , 14.5° and 14° , respectively. Stereophotogrammetric calculations showed a correction at the operation of 16.2° . Loss of correction was recorded up to the 8th week and the final correction was 13° . Twelve weeks after the operation the valgus deviation was 2° .

Sagittal plane. On tibial radiographs a rotation forwards of the distal segment was measured to 0.5° at the operation and this angle increased during the healing period to 3° at the final control. Stereophotogrammetric calculations showed a value of 5.7° forward rotation of the distal segment immediately after the operation and this increased to 6.6° at the 12-week control.

Transverse plane. At the first postoperative stereo control there was only a minor rotation in this plane, amounting to 0.8° inwards. During the post-operative period further inward rotation of the distal segment was found of at most 4.6° at 5 weeks and finally 3.3° at 12 weeks.

Case C. The preoperative varus deformity was measured to 10° . An over-correction to 4° of valgus was intended.

Frontal plane. On tibial radiographs a correction of 16.5° was measured peroperatively. Only small changes were seen during the healing period and at 21 weeks the correction was 16.5° . Stereo calculations showed a peroperative correction of 18.5° and there was only a minor change during the healing period with a final correction of 16.9° . The 21-week control showed a valgus deviation of 5.5° , i.e. a final correction of 15.5° versus the desired 14° .

Sagittal plane. On tibial radiographs a forward rotation by 5° of the distal segment was recorded initially which decreased during the healing period to 3° at the final control. Stereo calculations showed an initial angulation forwards of 4.5° which decreased to 3.1° at the final control.

Transverse plane. Stereo calculations gave an inward rotation of the distal segment of 5.5° peroperatively. This increased during the healing period and ended up with 7.7° .

Translational movements

The translations presented here are those of three defined points in the distal segment at the level of the osteotomy plane, one situated medially, one anteriorly and one laterally as described above. The three-dimensional translations caused by the osteotomy and those from the first to the last postoperative examination are presented in Table 4.

Case A. On the tibial radiograph the translation along the transverse axis at the medial cortex was less than 1 mm.

Transverse axis. The medial and lateral points showed only minor translation movements along the transverse axis, both over the osteotomy and during the postoperative course, but the anterior point showed a greater translation, 2.6 and 1.6 mm medially, respectively. The cause of this is the inward

rotation of the distal segment, and the position of the axis of rotation approximately on a line joining the medial and the lateral points.

Table 4. Translations (mm) caused by the osteotomy and from the first to last unloaded postoperative examination for points in the osteotomy plane of the distal segment given in relation to the proximal segment. The X-axis is a transverse axis, the Y-axis a longitudinal axis, and the Z-axis a sagittal axis (Fig. 3). Translations are given positive laterally (X-axis), cranially (Y-axis) and anteriorly (Z-axis).

Case	Point	Translation caused by the osteotomy			Translation during the postoperative course		
		X-axis	Y-axis	Z-axis	X-axis	Y-axis	Z-axis
A	Medial	-0.5	-1.6	-0.9	0.3	3.0	-1.9
	Anterior	-2.6	6.9	-0.8	-1.6	1.9	-0.6
	Lateral	-0.4	6.8	1.1	0.1	1.9	0.7
B	Medial	-1.6	-1.9	-0.7	-1.8	3.0	0.3
	Anterior	-2.6	7.0	-1.0	-3.7	2.5	1.3
	Lateral	0.2	12.8	0.0	-2.7	0.5	3.2
C	Medial	0.7	-1.4	-0.5	-0.5	2.4	-0.6
	Anterior	-2.2	9.6	1.4	-1.3	1.0	0.7
	Lateral	2.8	13.3	3.7	-0.2	1.5	1.0

Longitudinal axis. Over the osteotomy, translations along this axis mainly reflect rotations in the frontal plane. It was noted that a gap of 1.6 mm was formed medially but also that the compression did not vary linearly with the distance from the medial aspect, which reflects the three-dimensional character of the wedge removed. During the postoperative course there was compression in the whole osteotomy plane, largest medially (3 mm) but considerable (about 2 mm) both anteriorly and laterally.

Sagittal axis. Translational movements were relatively small along this axis both over the osteotomy and during the postoperative period. The different directions of translations at the medial and lateral points reflect the inward rotation mentioned above.

Case B. On the tibial radiograph 1-2 mm translation medially was recorded at the medial cortex.

Transverse axis. The operation caused 1.6 mm medial translation of the medial point and 0.2 mm lateral translation of the lateral point. During the postoperative period further medial translation was recorded, 1.8 mm at the medial point and 2.7 mm at the lateral. Here also an inward rotation explains the difference between the medial and lateral points.

Longitudinal axis. Peroperatively there was also in this case a small gap (1.9 mm) at the medial point. The compression at the anterior and lateral point varied rather linearly (7 mm and 13 mm, respectively). During the postoperative course the medial gap was closed and the compression was 3.0 mm, but the lateral compression was only 0.5 mm.

Sagittal axis. Only small translations backwards were caused by the operation, 1.0 mm at the anterior point and 0.7 mm at the medial point. During the postoperative period the distal segment moved forwards. The large anterior translation of the lateral point reflects the inward rotation.

Case C. On the tibial radiograph the translation along the transverse axis at the medial cortex was less than 1 mm.

Transverse axis. A translation laterally was found peroperatively, 0.7 mm at the medial and 2.8 mm at the lateral point, respectively. The medial translation (2.2 mm) at the anterior point indicates an inward rotation of the distal segment with the axis of rotation rather close to the medial point. During the postoperative course there were only minor translations.

Longitudinal axis. The operation caused also in this case a minor gap at the medial point of 1.4 mm. During the postoperative course the compression medially was 2.4 mm and 1.0 mm and 1.5 mm anteriorly and laterally, respectively.

Sagittal axis. Along this axis the operation caused translations in different directions, 0.5 mm backwards and 3.7 mm forwards at the medial and lateral point, respectively, reflecting the inward rotation of the distal segment. This rotation continued during the postoperative period resulting in translations 0.6 mm backwards at the medial point and 1.0 mm forwards at the lateral point.

Translational movements at the femoro-tibial joints

Of the two cases with femoral balls one was excluded because no loaded pre-operative stereo roentgenogram was obtained. In the other (Case A) the change in relation between the joint surfaces of the femoro-tibial articulations was recorded before and after the osteotomy. A point at the inferior joint surface of both the medial and lateral femoral condyles was defined. The translations between these points and the proximal tibial segment were determined between the loaded recordings before the osteotomy and 10 weeks after. A lateral translation of the femur was found, 1.2 mm for the medial and 1.3 mm for the lateral condyle.

Precision

By re-evaluating eight stereo film pairs and calculating the "movements" between the two evaluations the standard deviation for rotation in the frontal plane (rotation about the Z-axis) was found to be 0.21° . The rotation in the sagittal plane (about the X-axis) had a standard deviation of 0.18° , and the corresponding value for the transverse plane (Y-axis) was 0.13° .

Standard deviations for translations of the points in the osteotomy plane were calculated from the same re-evaluations and were found to be 0.06 mm for the X-axis (transverse axis), 0.08 mm for the Y-axis (longitudinal axis), and 0.09 mm for the Z-axis (sagittal axis).

Stability

When the plaster was removed, at 5-6 weeks postoperatively, the osteotomies

were stable by clinical examination but unstable by roentgen stereophotogrammetry. Cases A and C had the major angular instability in the sagittal plane, 3.2° and 1.5° , respectively, but in Case B the major angulation, 1.9° , occurred in the frontal plane (Table 3). The maximum compression was 1.4 mm for Cases A and B, and 0.9 mm for Case C. At the 8-10 week controls and later, no angular change exceeded 1.1° and no compression exceeded 0.5 mm.

With strict use of statistical principles a definite stability was only obtained for Case C, which showed no significant rotations and translations (less than 0.2 mm) both at the 13 and 18 week controls. The intervening examination, at 9 weeks, between the definitely unstable and stable conditions, can be regarded as having a limit value with a maximum rotation of 0.7° and a maximum compression of 0.4 mm.

In Cases A and B, there were after the 10 and 8 week controls, respectively, also limit values with maximum angular changes of 0.6° and maximum translations of 0.3 and 0.4 mm, respectively.

DISCUSSION

Remarks on the radiographic examinations and measurements. There are in the literature only a few reports on standardized radiographic methods measuring correction angles in high tibial osteotomy (Myrnerets 1979, Hagstedt et al. 1980). Reported errors of measurement are 1° - 4° (Hagstedt 1974) and 1° (Myrnerets 1979).

The three patients in this study were examined pre- and postoperatively according to principles introduced by Maquet et al. (1967), Norman (1974), Hagstedt et al. (1980) and further developed by Egund (1981). Prerequisites of the method are reproducible projections and angular measurements in relation to the long tibial axis in the frontal plane.

Remarks on the roentgen stereophotogrammetric analysis. In order to correlate the values from the stereo calculations with measurements on tibial radiographs the same frontal plane was used. It is only important to adjust the position of the leg to this frontal plane at the first stereo roentgen examination. At all following investigations the computer reproduces this original plane and the displacements are given about and along axes in this plane. The correct position is checked on the lateral roentgenogram of the knee in the calibration cage.

Implant stability in the bone is fundamental and is checked in the calculations. It proved to be important to place the balls at least half a centimeter from the osteotomy line in order to avoid loosening caused by the bone resorption during the first postoperative weeks. One ball in Case A was too close to the osteotomy and thus became loose during this period. The ball was then stabilized in a new position when the osteotomy was healed. Periosteally implanted balls showed also instability (Fig. 1b).

Precision and accuracy. The technical accuracy of stereo measurements is approximately equal to the precision (Selvik 1974). This means that no errors other than measurement errors, accounted for when re-evaluating films in the precision tests, are introduced when comparing investigations at different occasions if the implants are stable in the bone. In the kinematic calculations the rigid-body model of the implants is checked and the model was satisfied but in Case A, where after exclusion of the ball with gross instability a minor instability was noted in both segments, explained by periosteal position of one implant in each segment. This was of concern only in the proximal segment, as a third implant stable during the investigated period was hidden at some examinations.

However, when implant stability is achieved, the true values for rotations and translations can be given with errors (standard deviations) of 0.2° and 0.1 mm or less, which is about ten times higher accuracy than reported in earlier works on tibial osteotomies.

Validity of the radiographic measurements. The difference between the radiographically measured correction and the values from the stereo calculations in the frontal plane was greatest at the first postoperative control with a maximum of 3.3° . No difference exceeded 1° at the last control.

The great difference postoperatively may reflect the absence of rigid internal fixation. The instability at one week was $2^{\circ} - 4^{\circ}$ between the unloaded and loaded stereo examinations, and the patient was moved between the conventional and the stereo examinations.

Calculating the root mean square discrepancy between the stereo and conventional technique (14 measurements) the discrepancy found in the frontal plane was 1.3° . In the sagittal plane the root mean square discrepancy was 4.0° . The higher value may reflect the lesser accuracy in determining the short tibial axis compared with the long axis in the frontal plane.

Due to the law of error propagation the stereo error of 0.2° has no appreciable influence on the total discrepancy between the values of stereo and conventional technique. It is thus concluded that if accepting only technical errors in the stereo measurements the present radiographic technique has an accuracy of 1.3° (standard deviation) for measuring corrections in the frontal plane. This is to be compared with the "precision" value of 1° obtained by Myrnerets (1979) when remeasuring tibial radiographs.

Angular correction at the operation. Generally at the osteotomy the aim is to achieve a correction in the frontal plane (Maquet et al. 1967, Bauer et al. 1969, Coventry 1979, Myrnerets 1979). In some cases also a correction in the sagittal plane is desirable to compensate for an extension defect. Maquet has also combined high tibial osteotomy with a translation forward of the distal fragment in the sagittal plane in order to diminish the load in the femoro-patellar joint.

In the three cases of this study only correction in the frontal plane was desired. The osteotomies were technically good. Despite this all three

osteotomies showed angular and translational movements in all three planes. The intended angular change in the frontal plane was achieved in all cases but in addition up to 9° angular changes were observed in the other two planes.

These not intended "minor" rotations seem not to have any clinical significance. Hagstedt (1974) had on average 10° forward tilt of the proximal fragment but the result was poor only when the tilt was more than 20° . Myrnerets (1979) had on average 6.2° forward tilt but no significant influence on the clinical results was observed.

Translational movements. In our cases there was no intention to produce translations along the transverse and sagittal axes. However, in all cases translations were recorded at the operation and during the healing along all axes. Closing of the wedge space caused the segments to approach each other and created thus a compression. When this compression was almost the same anteriorly as laterally this reflects (Case A) wedging also in the sagittal plane. Small gaps medially were observed in all cases at the postoperative control and they probably indicated a forced valgisation during the internal fixation and when modelling the plaster. On weight-bearing these gaps were closed.

There was good agreement for translations along the transverse axis between the conventional and the stereo measurements for the only comparable point at the medial cortex.

A further result of the osteotomy was a translation along the transverse axis between the femoral and tibial joint surfaces. The tibial joint surface translated medially between the loaded preoperative examination and that at the 10-week control (Case A). This change in position was recognized by Egund and Tjörnstrand (1980), who suggested that it creates new cartilage contact in the lateral portion of the medial compartment and may contribute to regrowth of cartilage within the unloaded joint surface.

Stability. At the clinical examination none of the knees was unstable when the plaster was removed after 5-6 weeks. On the tibial radiographs only angular changes of 1° could be measured after the third week. At the plaster removal, however, highly significant movements were measured by roentgen stereophotogrammetry, amounting up to 2° - 3° and 1.5 mm in rotation and translation, respectively. After the 10-week control there were limit values in Cases A and B but no significant mobility in Case C.

Myrnerets (1979) measuring on tibial radiographs reported a loss of correction more than 1° (mean value) at the time of plaster removal 6 weeks postoperatively. He connected this loss of correction with increased weight-bearing and recommended 10 weeks before full weight-bearing. In our cases the change in correction during the healing period was best recorded by the stereo calculations. There were changes of correction in all knees and at the final control there was a gain in Case A but loss of correction in Cases B and C, of 3.2° and 1.6° , respectively. Changes were recorded both during the plaster time and after plaster removal. The amount of changes after plaster removal, however, were not at a level which convinces us (cf. also Hagstedt et al. 1980, Tjörnstrand et al. 1981b) to use a longer immobilisation and non-weight-bearing period, which has been suggested by Coventry (1979) and Myrnerets (1979).

CONCLUSIONS

1. Roentgen stereophotogrammetry is a superior method for measuring angular and translational movements in all three planes.
2. Angular changes in the frontal plane at high tibial osteotomy are measured with sufficient accuracy with the present radiographic technique.
3. The surgical accuracy in obtaining the intended correction in the frontal plane is good, but high tibial osteotomy causes additional angular and translational movements in planes where correction is not intended.
4. Changes in correction and instability were measured by roentgen stereophotogrammetry after plaster removal.

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RESULTS OF SURGICAL TREATMENT FOR NON-UNION AFTER HIGH
TIBIAL OSTEOTOMY IN OSTEOARTHRITIS OF THE KNEE

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Results of Surgical Treatment for Non-Union after High Tibial Osteotomy in Osteoarthritis of the Knee

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ABSTRACT: In a series of 280 high tibial osteotomies performed for osteoarthritis of the knee between 1969 and 1975, there were ten cases of pseudarthrosis, an incidence of 3.6 per cent. These ten knees (and an additional two that were referred to us) were reoperated on. In most cases the pseudarthrosis was resected and stabilized with the Charnley transfixation-compression method. Other procedures involved resection without compression (one knee), compression blade-plate fixation, and arthroplasty with a hinge endoprosthesis. All osteotomies healed eventually with the knee in satisfactory position. In spite of the initial non-union and repeated operation, all twelve patients eventually had satisfactory correction of the preosteotomy deformity, and none had a loss in walking ability. All but two patients had freedom from pain. We concluded that patients with non-union following high tibial osteotomy for osteoarthritis of the knee should undergo resection of the pseudarthrosis and transfixation compression as the treatment of choice. Endoprosthetic replacement then can be used as a salvage procedure if it is needed.

As treatment for osteoarthritis of the knee, high tibial osteotomy is perhaps the surgical procedure of choice, particularly in the presence of pain and valgus or varus deformity of any important degree. The operation has few risks, and there have been several reports of large series of procedures in which non-union of the osteotomy either was not mentioned^{4,5,6,8,9} or was considered to be a rarity². We saw ten non-unions in a series of 280 cases and are now reporting in detail our experience with the complication, including two additional cases referred to us.

Material

During 1969 to 1975, 280 high tibial osteotomies were performed for osteoarthritis of the knee at the Department of Orthopaedic Surgery, University Hospital in Lund, Sweden. The clinical material has been presented in detail⁷ for the years 1969 to 1972 and among the 152 cases there were eight non-unions. Among the 128 knees operated on between 1973 and 1975, another two non-unions were recorded. In addition, two cases of non-union following tibial osteotomy were referred to our department from other hospitals during the period of investigation. The clinical material described therefore comprises twelve knees

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Case	Sex	Age (Yrs.)	Com- partment	Functional State before Primary Tibial Osteotomy				
				Range of Knee Flexion (Deg.)	Stability in Extension	Femoro- tibial Angle* (Deg.)	Walking Distance (m)	Walking Support
1	M	62	Med.	100	—	205	1000	—
2	F	58	Med.	100	+	185	500	—
3	F	77	Med.	100	+	190	1000	—
4	F	67	Med.	130	—	185	100	—
5	F	61	Med.	120	—	190	100	+
6	F	72	Lat.	100	—	170	500	—
7	F	55	Med.	105	+	180	500	—
8	F	59	Med.	120	—	190	100	+
9	F	70	Med.	100	—	185	500	+
10	M	74	Med.	130	—	185	500	+
11	F	71	Med.	90	—	210	500	+
12	F	76	Med.	100	—	185	200	+

* Any femorotibial angle of less than 180 degrees is a valgus position.

†ST = staple; ILO = infraligament osteotomy (dome osteotomy); CC = Charnley compression fixation; AO = AO compression angular blade-plate; and GUE = Guepar endoprosthesis.

reoperated on for non-union following tibial osteotomy performed for osteoarthritis of the knee.

Methods

Different factors that may have had an influence on the development of the non-union were analyzed: age, sex, type and degree of arthrosis¹, preoperative and postoperative status, complicating diseases, height, and weight were

compared with the source material of the 280 osteotomies. No obvious cause of non-union emerged.

Osteotomy

A closing wedge osteotomy proximal to the tibial tuberosity was performed in all 280 knees, including the ten that form the source material for this study. However, in the two additional patients who were referred to us, the

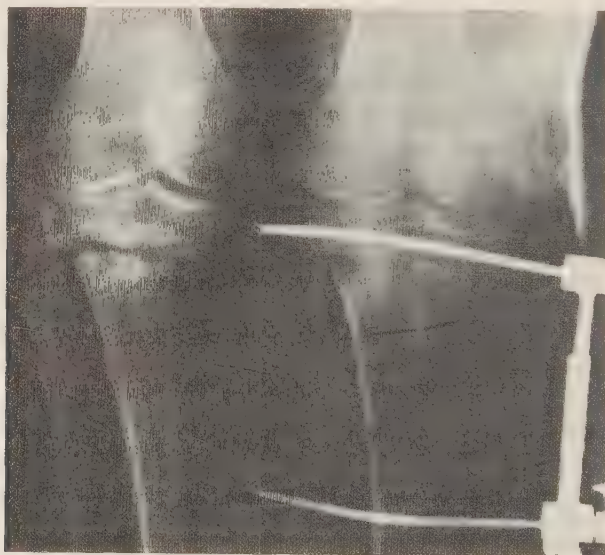


FIG. 1

Case 6, a seventy-two-year-old woman with primary lateral osteoarthritis of the knee. Four months after a varus osteotomy, the roentgenogram (left) shows no healing and instability is evident clinically. Six months after the osteotomy, reoperation was performed with Charnley compression fixation (right).

I

Date of Primary Osteotomy	Reosteotomy for Loss of Correction†	First Pseudarthrosis Operation†	Final Functional Status				
			Range of Knee Flexion (Deg.)	Stability	Femoro-tibial Angle (Deg.)	Walking Distance (m)	Walking Support
9/71	—	3/72 CC	100	—	185	400	+
6/71	—	2/72 CC	120	—	175	500	—
4/71	9/71 ST	1/72 CC	80	—	170	1000	—
3/70	5/71 ST	2/72 CC	120	+	175	1000	—
10/71	—	6/72 CC	110	+	175	100	+
4/75	—	10/75 CC	115	—	185	1000	—
6/71	—	11/71 CC	90	—	175	500	—
6/71	3/72 ILO	10/72 AO	120	—	175	200	—
9/71	7/72 ILO	5/73 AO	120	+	185	500	+
2/70	—	1/71 ST	120	+	175	500	—
2/71	—	5/73 GUE	30	+	175	500	—
4/73	—	1/74 CC	90	+	175	500	—

non-union had occurred after a dome osteotomy distal to the tibial tuberosity had been performed for correction of a closing wedge osteotomy that had failed to correct the initial deformity.

The closing wedge osteotomy was performed through an anterior transverse incision. The site of osteotomy was exposed and the posterior structures were protected by osteotomy hooks. In six of the ten knees the osteotomy fragments were stabilized with a Blount staple and in four no internal fixation was used. In one dome osteotomy a Charnley compression instrument had been added for fixation, and in one no internal fixation had been used. A plaster cast from the groin to the ankle was used for six to fourteen weeks in all cases.

The patients were encouraged to walk in the cast with weight-bearing as tolerated.

Reoperation

In seven cases resection of the pseudarthrosis com-

bined with correction of any deformity was the procedure followed and the Charnley compression instrument was used for fixation. A plaster cast was worn for six to nine weeks with partial weight-bearing allowed. In six of these knees the tibial fragments were compressed. In one the compression had to be applied across the joint because the proximal tibial fragment was very thin.

In one knee we resected the pseudarthrosis and used a bone graft from the iliac crest. Fixation was accomplished with a Blount staple. In two knees we resected the pseudarthrosis and used an angulated AO compression plate for fixation. Motion of the knee was encouraged immediately after operation but weight-bearing was not allowed. In the last two patients a total joint replacement was performed with the Guepar hinge endoprosthesis. One of these followed one failed attempt at resection of the pseudarthrosis with the Charnley compression instrument used for fixation. Mobilization with full weight-bearing was encouraged immediately.



FIG. 2

Case 7, a fifty-five-year-old woman with a history of a tibial condylar fracture on the left. Four months after tibial osteotomy there is varus malposition and instability (left). Five months after osteotomy, reoperation was done with Charnley compression fixation (right).

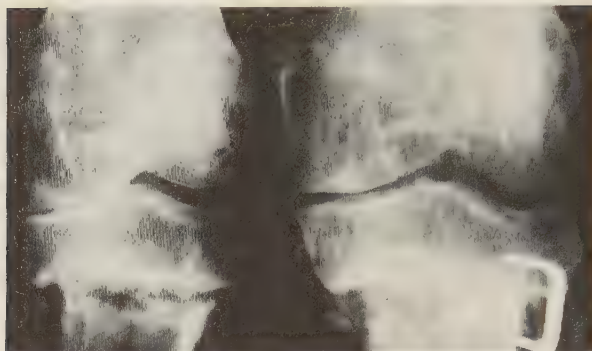


FIG. 3

Case 10, a seventy-four-year-old man with primary medial osteoarthritis of the knee. Ten months after tibial osteotomy there is instability, and a roentgenogram shows the pseudarthrosis (left). Reoperation was carried out eleven months after the osteotomy: resection, bone-grafting, and fixation with a Blount staple (right). Healing resulted.

The follow-up after the operation for pseudarthrosis was one year or more in all cases. The status of the patient before the first osteotomy was compared with the postoperative status one year after the operation for pseudarthrosis. We studied the mobility, stability, freedom from pain, walking distance, walking support, and frontal (varus-valgus) angle of the knee on weight-bearing. The latter measurement was made clinically with a goniometer, with the patient standing on both lower extremities.

Results

Before the initial osteotomy all twelve knees had more than 90 degrees of flexion; three were stable but none were free of pain. One year after reoperation, we evaluated the results in the twelve patients with respect to mobility (range of flexion of 90 degrees or more), stability, and pain. Four had good motion and stability and were free of pain; four were pain-free and had good mobility, but showed some significant instability; two had good mobility and stability but continued to have some pain; one had no pain and good stability, but less than 90 degrees of motion; and the last, while free of pain, had neither good motion nor stability.

One patient increased his walking distance considerably. In the others, except for Case 1, there was no significant change in walking ability (Table I).

The final correction of the preoperative deformity was satisfactory in all cases. It should be observed that in one knee (Case 6) the preoperative valgus was changed to slight varus and that in another (Case 3) the postoperative valgus had been overcorrected from preoperative varus deformity. Five knees were originally in varus angulation of 10 degrees or more; six, in zero to 10 degrees of varus; one, in 5 to 10 degrees of valgus; and none, in more than 10 degrees of valgus. After operation no knee had more than 10 degrees of varus angulation; three had zero to 10 de-

grees of varus; nine had zero to ten degrees of valgus; and none was in more than 10 degrees of valgus angulation.

Discussion

Even though some authors^{2,5,6,8,11} have reported occasional cases of non-union after tibial osteotomy, the operation provides such favorable conditions for healing that we have found only one previous report³ of treatment of a resulting non-union: two knees operated on with the Walldius endoprosthesis, of which one became infected and eventually resulted in an arthrodesis.

In the present series there were eight pseudarthroses after primary osteotomy, and four after reoperation for loss of correction (Table I). The surgical treatment of the non-union was either resection of the pseudarthrosis or, in two cases, arthroplasty with insertion of a hinge endoprosthesis. For the majority of knees the resection was chosen at least partly for the same reason that a primary osteotomy rather than an arthroplasty had been performed originally — to avoid the hazards of endoprosthetic arthroplasty of the knee. In eight of the knees that had resection, stability was achieved with the Charnley compression method; in seven of them satisfactory position was achieved with a good result. The eighth knee, a failure after use of Charnley compression, then had a Guepar hinge endoprosthesis inserted, and the result after that procedure was satisfactory. A dome osteotomy was carried out in two knees as a second operation after correction had been lost. An AO compression blade-plate was used in those two knees and healing ensued. In Case 10 the resection was stabilized with a Blount staple and a plaster cast, and the osteotomy healed in satisfactory position.

Of these twelve patients, pseudarthrosis developed in four knees after a reoperation and in eight, after primary surgery. This incidence does not differ very much from the figures of MacIntosh and Welsh (3 per cent) or of Jackson

and Waugh (2.2 per cent), but is somewhat higher than those of Bauer and associates and of Kettelkamp and co-workers, who both noted an incidence of one pseudarthrosis in sixty-six knees.

The repeat osteotomy in two knees was performed distal to the tibial tubercle. Today this procedure is known to increase the likelihood of delayed union¹⁰. One technical point is worthy of note: If an extensive explora-

tion is done in which the incision traverses the periosteal and fascial structures on the medial side of the tibia, the osteotomy will be hard to stabilize with or without staples. If instead one avoids incising the medial soft tissues and uses the hinge effect when closing the osteotomy, with a staple for fixation, stability is increased. Using this technique in our most recent sixty osteotomies, we had no pseudarthroses.

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